NACA

RESEARCH MEMORANDUM

LONGITUDINAL AND LATERAL STABILITY AND CONTROL CHARACTERISTICS AT MACH NUMBER 2.01 OF A 60° DELTA-WING AIRPLANE CONFIGURATION EQUIPPED WITH A CANARD CONTROL AND WITH WING TRAILING-EDGE FLAP CONTROLS

By M. Leroy Spearman and Cornelius Driver

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NATIONAL ADVISORY COMMITTEE
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LONGITUDINAL AND LATERAL STABILITY AND CONTROL CHARACTERISTICS AT MACH NUMBER 2.01 OF A 60° DELTA-WING AIRPLANE CONFIGURATION EQUIPPED WITH A CANARD CONTROL AND WITH WING TRAILING-EDGE FLAP CONTROLS

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SUMMARY

An investigation has been made in the Langley 4- by 4-foot supersonic pressure tunnel at a Mach number of 2.01 to determine the longitudinal and lateral stability and control characteristics of a 60° delta-wing airplane configuration equipped with a trapezoidal canard control and with wing trailing-edge flap controls. The investigation included studies of the flap control both with and without the canard surface and studies of the canard control alone and in conjunction with flap control. Each of the control arrangements was investigated for a configuration having either a single body-mounted vertical tail or twin wing-mounted vertical tails.

The results indicated that for a constant static margin, the maximum values of trim lift and trim lift-drag ratio were generally higher with the canard control than with the trailing-edge flap control. However, the trimming advantages of the canard control over the flap control decrease as the static margin decreases. For a constant static margin, there was generally little difference in the trim characteristics with the flap control whether the canard surface was on or off. However, for the same static margin, the center of gravity must be farther rearward with the canard off and hence the effects on directional stability must be considered. When used in conjunction with the canard control, the most significant contribution of the flap control was an increase in the maximum trim lift. The highest maximum values of lift-drag ratio were obtained when trimming with the canard surface alone. Only for a small lift range above the lift coefficient for maximum lift-drag ratio did the use of the flap in conjunction with the canard control provide a higher lift-drag ratio than did the canard control alone.

The twin-tail configuration, in comparison with the single-tail configuration, provided a stabilizing increment in directional stability that increased somewhat with increasing angle of attack as a result of a favorable sidewash induced on the tails by the canard-surface flow field.

INTRODUCTION

A research program is underway at the Langley 4- by 4-foot supersonic pressure tunnel to determine the aerodynamic characteristics of several canard airplane configurations at supersonic speeds. The longitudinal and lateral stability characteristics for configurations having a trapezoidal wing and a 60° delta wing are presented in reference 1 for Mach numbers of 1.41 and 2.01. The effects of canard surface size on the aerodynamic characteristics of the same two configurations are presented in reference 2.

The configurations included in references 1 and 2 made use of only the canard surfaces as a means of longitudinal control. This investigation has subsequently been extended for the 60° delta-wing configuration to include the effects of constant-chord plain trailing-edge flap controls extended over the inboard 40 percent of the exposed wing semispan. The flaps were investigated as a means of longitudinal control both without the canard surface and in conjunction with the canard surface. The investigation included the effects of the controls for configurations having two different vertical-tail arrangements. One arrangement made use of a single body-mounted vertical tail. The other made use of twin wing-mounted vertical tails that had a total area twice that for the body-mounted tail and were located outboard of the canard surface wake in the hope that a favorable sidewash effect might be realized. This paper presents the results of this investigation for a Mach number of 2.01.

SYMBOLS

The results are presented as force and moment coefficients with lift, drag, and pitching-moment coefficients referred to the stability-axis system and rolling-moment, yawing-moment, and side-force coefficients referred to the body-axis system. (See fig. 1.) The reference center of moments was at fuselage station 25 (fig. 2(a)) which corresponds to the 7.75-percent point of the wing mean geometric chord projected to the fuselage center line.

C_L lift coefficient, F_L/qS

C_D drag coefficient, F_D'/qS

C_m pitching-moment coefficient, $M_{Y_s}/qS\bar{c}$

C_l rolling-moment coefficient, M_X/qSb

C_n yawing-moment coefficient, M_Z/qSb

C_Y side-force coefficient, F_Y/qS

F_L lift force

F_D' drag force

M_Y moment about Y-axis

M_X moment about X-axis

M_Z moment about Z-axis

F_Y side force

q free-stream dynamic pressure, lb/sq ft

S wing area including fuselage intercept, 1.53 sq ft

b wing span, 1.88 ft

$\bar{c}$ wing mean geometric chord, 1.086 ft

M free-stream Mach number

α angle of attack, deg

β angle of sideslip, deg

δ_c deflection angle of canard with respect to fuselage reference line, positive when trailing edge is down, deg

δ_f deflection angle of trailing-edge flap with respect to wing chord plane, positive when trailing edge is down, deg

L/D lift-drag ratio, C_L/C_D

C_{n_β} directional-stability parameter, $\Delta C_n/\Delta\beta$

C_{l_β} effective-dihedral parameter, $\Delta C_l/\Delta\beta$

C_{Y_β} side-force parameter, $\Delta C_Y/\Delta\beta$

Subscripts:

L left

R right

s stability axis

MODELS AND APPARATUS

Details of the model are shown in figures 2 and 3 and the geometric characteristics are presented in table I. Coordinates for the body are presented in table II.

The canard surface had a ratio of exposed area to total wing area of 0.062. The trailing-edge flaps had an area equal to the exposed area of the canard surface. The canard control was motor driven and deflections were set by remote control whereas the flap control deflections were set manually.

Details of the vertical tail, which differs from that used in references 1 and 2, are shown in figure 2(b). Both the body-mounted tail and the wing-mounted tails had the same dimensions. The directional surfaces differed further from those shown in references 1 and 2 in that no ventral fins were used.

The model was mounted in the tunnel on a remote-controlled rotary sting and force measurements were made through the use of a six-component internal strain-gage balance.

TESTS, CORRECTIONS, AND ACCURACY

The tests were made at a Mach number of 2.01 with a stagnation pressure of 10 pounds per square inch and a stagnation temperature of 100° F. The Reynolds number based on $\bar{c}$ for the wing was 2.68×10^6. The stagnation dewpoint was maintained sufficiently low (-25° F or less) so that no condensation effects were encountered in the test section.

The angles of attack and sideslip were corrected for the deflection of the balance and sting under load. The base pressure was measured and the drag was adjusted to a base pressure equal to free-stream static pressure.

The estimated accuracy of the individual measured quantities is as follows:

C_L	±0.0003
C_D	±0.0010
C_m	±0.0004
C_l	±0.0004
C_n	±0.0001
C_Y	±0.0015
α, deg	±0.2
β, deg	±0.2
δ_c, deg	±0.1
δ_f, deg	±0.1
M	±0.01

The tests were made through an angle-of-attack range from about 0° to 28°. The sideslip derivatives C_{n_β}, C_{l_β}, and C_{Y_β} were obtained from the incremental values measured through the angle-of-attack range at constant sideslip angles of about 0° and 4°.

DISCUSSION

Longitudinal Stability

The effects of canard control deflection on the aerodynamic characteristics in pitch for trailing-edge flap deflections of 0°, -10°, -20°, and -30° are shown in figure 4 for the single-vertical-tail configuration and in figure 5 for the twin-vertical-tail configuration. The effects of trailing-edge flap deflection on the aerodynamic characteristics in pitch with the canard surface off are shown in figures 6 and 7 for the single-tail and twin-tail configurations, respectively. As would be expected for a constant center-of-gravity position, the configurations with the canard control surfaces (figs. 4 and 5) provide lower static margins and higher controllability than the configurations with the canard surfaces removed (figs. 6 and 7). In fact, for the configurations with the canard surfaces removed, the static margin is so great and the controllability so low that it would be necessary to move the center of gravity rearward to permit trimming at the maximum L/D. (See figs. 6 and 7.)

A comparison of the longitudinal trim characteristics for the configurations with the canard control and with the trailing-edge flap control is presented in figure 8. This comparison is for a constant static margin of approximately 22 percent $\bar{c}$ which was the value obtained at the test center-of-gravity position for the configurations having the canard surface. For the flap control with the canard off, it was necessary to shift the center of gravity rearward approximately 15 percent $\bar{c}$ in order to obtain a static margin of 22 percent $\bar{c}$. The trim results (fig. 8) indicate a higher lift-curve slope, a higher maximum lift, a lower drag due to lift, and a higher maximum value of L/D with the canard control than with the flap control for a fixed static margin of 22 percent $\bar{c}$. There was relatively little difference in the trim results with the flap control whether the canard surface was on or off. The primary consideration in this case is the fact that the center-of-gravity position for the canard-off configuration is farther rearward than for the canard-on configuration and hence the effects on directional stability must be considered.

The advantages of the canard control over the flap control in improving longitudinal trim characteristics would, of course, be less for lower static margins. A comparison of the canard-control configuration with the flap-control tailless configuration (canard off) for a static margin of approximately 10 percent $\bar{c}$ is shown in figure 9. The configuration with the canard control still provides a higher maximum lift and a slightly higher maximum value of L/D. As the static margin approaches zero, each control system provides infinite longitudinal control effectiveness and the maximum values of L/D approach those obtained for the controls fixed at 0° deflection.

The longitudinal trim characteristics for the canard control used in conjunction with the trailing-edge flap control are presented in figure 10 for a static margin of approximately 22 percent $\bar{c}$. The most significant contribution of the flap deflection is an increase in the maximum trim lift. The maximum value of L/D is obtained using the canard control alone at a flap deflection of 0°. Only for a small lift range above the lift coefficient for maximum L/D does the use of the flap in conjunction with the canard control provide a higher value of L/D than that obtained with the canard alone.

Although the effects of the vertical tail on the longitudinal characteristics are relatively small, an examination of the trim characteristics reveals that the minimum drag is measurably lower and the values of L/D generally higher for the single-tail configurations than for the twin-tail configurations.

Lateral Stability

The primary purpose of the twin-vertical-tail arrangement, of course, is to provide a higher level of directional stability particularly in those cases where it may be desirable to shift the center of gravity rearward in order to improve the longitudinal trim characteristics.

The effect of vertical-tail arrangement on the sideslip derivatives for the configuration with and without the canard surface is shown in figure 11. As might be expected, the twin-tail arrangement provides about twice as much directional stability as does the single-tail arrangement at $\alpha = 0^{\circ}$. With the canard surface off, the increase in C_{n_β} provided by the twin tail in comparison with the single tail is about constant throughout the angle-of-attack range. With the canard surface on (fig. 11(b)), however, the stabilizing increments in C_{n_β} provided by the twin-tail in comparison with the single tail increase somewhat with increasing angle of attack as a result probably of a favorable sidewash induced on the tails by the canard-surface flow field.

Although the twin-tail arrangement in comparison with the single-tail arrangement indicates an increase both in $-C_{Y_\beta}$ and C_{n_β}, the change in C_{l_β} is relatively small. (See fig. 11.) This probably results from an interference effect of the vertical tails on the wing tips so that, in sideslip, the upwind tail would provide a positive pressure above the wing tip whereas the downwind tail would provide a negative pressure above the wing tip. In this manner a rolling moment would be induced on the wing that is opposite to the rolling moment to be expected from the side force on the vertical tails.

The effects of the canard surface on the sideslip derivatives (fig. 12) generally indicate a small reduction in C_{n_β} with angle of attack for the single-tail arrangement and an increase in C_{n_β} with angle of attack for the twin-tail arrangement. Apparently, this is a result of the single tail being mounted in the adverse sidewash field from the canard whereas the twin tails are mounted in such a position as to be in a favorable sidewash field. In addition, the presence of the canard surface generally causes an increase in the effective dihedral $\left(\text{more negative } C_{l_\beta}\right)$ for both tail arrangements. This is probably caused by a decrease in lift from the downwind wing panel resulting from the canard surface downwash.

Deflection of the canard control to 15° (fig. 13) apparently accentuates the wake effects from the canard surface in that C_{n_β} is generally further reduced for the single-tail arrangement and generally increased for the twin-tail arrangement. In addition, deflection of the canard generally causes a further increase in $-C_{l_\beta}$ for both tail arrangements.

Deflection of the trailing-edge flap control to -30° had little effect on the sideslip derivatives for the single-tail configuration with the canard off (fig. 14(a)). However, for the twin-tail configuration with the canard off (fig. 14(b)), deflection of the trailing-edge flap resulted in some increase in C_{n_β}, $-C_{l_\beta}$, and $-C_{Y_\beta}$. This effect is probably caused by a transmittal of positive pressures from the downwind flap to the downwind vertical-tail panel.

Although the sideslip derivatives with combined canard and flap deflections are not shown, the results indicated the effects of deflection for each control to be independent of deflection of the other control.

A limited investigation of the lateral control effectiveness of the trailing-edge flap was made at $\beta = 0^\circ$ wherein only the right-hand flap was deflected -30° while the left-hand flap remained undeflected. The results for the twin-tail configuration (fig. 15) indicate a positive roll effectiveness and adverse yawing moments that decrease only slightly with increasing angle of attack. The adverse yawing moments probably result from a transmittal of positive pressures from the deflected flap to the inboard side of the right-hand tail.

CONCLUSIONS

An investigation has been conducted in the Langley 4- by 4-foot supersonic pressure tunnel at a Mach number of 2.01 to determine the stability and control characteristics of a 60° delta-wing configuration equipped with a canard control surface and with wing trailing-edge flap control surfaces. The results of the investigation indicated the following conclusions:

1. For a constant static margin, the maximum values of trim lift and trim lift-drag ratio were generally higher with the canard control than with the trailing-edge flap control. However, the trimming advantages of the canard control over the flap control decrease as the static margin is decreased.

2. For a constant static margin, there was generally little difference in the trim characteristics with the flap control whether the canard surface was on or off. However, for the same static margin, the center of gravity must be farther rearward with the canard off and hence the effects on directional stability must be considered.

3. When used in conjunction with the canard control, the most significant contribution of the flap control was an increase in the maximum

trim lift. The highest maximum value of lift-drag ratio was obtained with the canard control alone. Only for a small lift range above the lift coefficient for maximum lift-drag ratio did the use of the flap in conjunction with the canard control provide a higher lift-drag ratio than that obtained with the canard control alone.

4. The twin-tail configuration, in comparison with the single-tail configuration, provided a stabilizing increment in directional stability that increased somewhat with increasing angle of attack as a result of a favorable sidewash induced on the tails by the canard-surface flow field.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., January 3, 1958.

REFERENCES

1. Driver, Cornelius: Longitudinal and Lateral Stability and Control Characteristics of Two Canard Airplane Configurations at Mach Numbers of 1.41 and 2.01. NACA RM L56L19, 1957.

2. Spearman, M. Leroy, and Driver, Cornelius: Effect of Canard Surface Size on Stability and Control Characteristics of Two Canard Airplane Configurations at Mach Numbers of 1.41 and 2.01. NACA RM L57L17a, 1958.

TABLE I

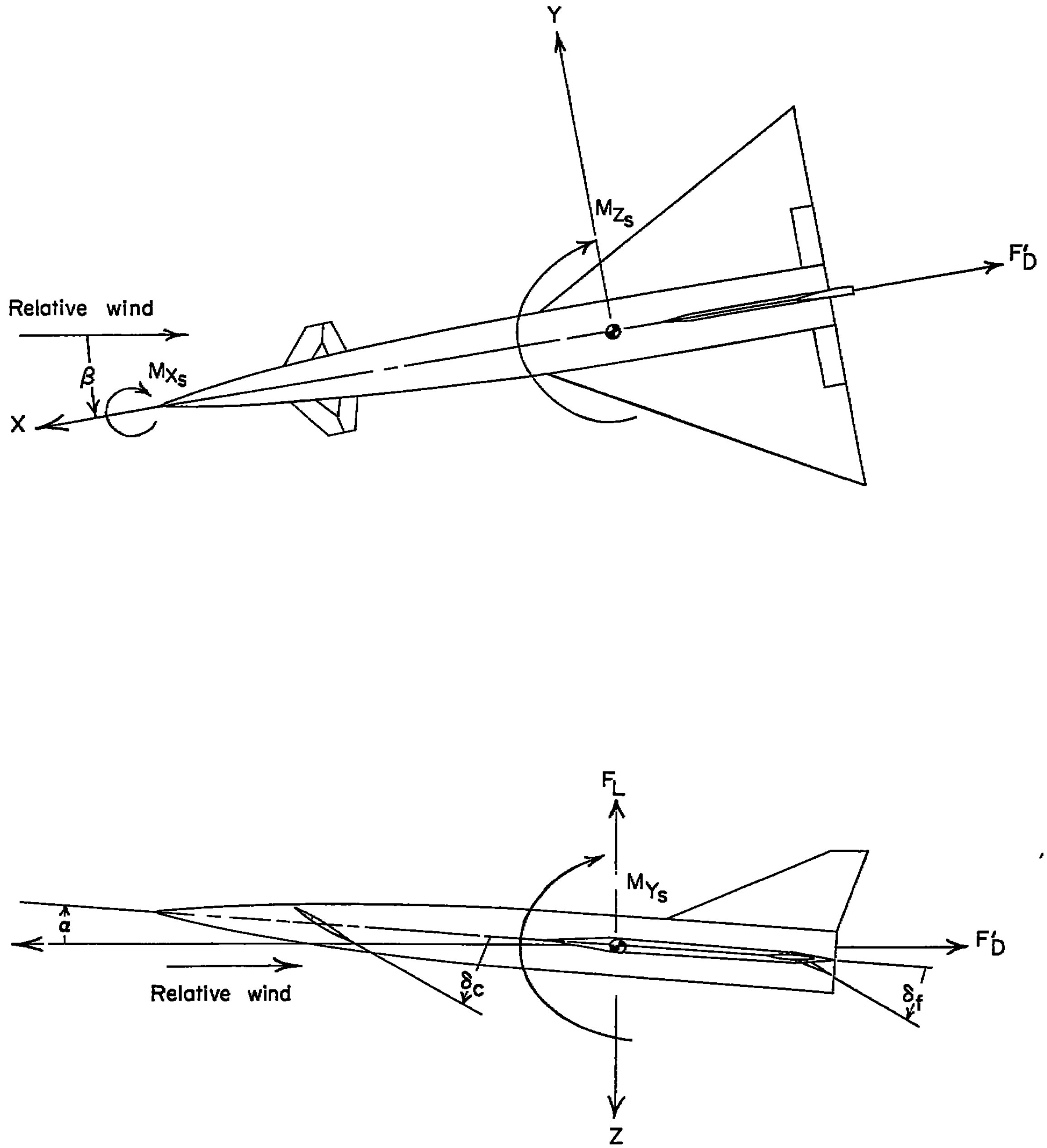
GEOMETRIC CHARACTERISTICS OF MODEL

Body:	
Maximum diameter, in.	3.50
Length, in.	37.00
Base area, sq in.	9.62
Fineness ratio	10.57
Wing:	
Span, in.	22.56
Chord at body center line, in.	19.541
Mean geometric chord, in.	13.027
Area, sq ft	1.53
Aspect ratio	2.31
Taper ratio	0
Sweep of leading edge, deg	60
Incidence angle, deg	0
Thickness ratio	0.036
Section	Hexagonal
Canard surface:	
Area, exposed, sq in.	13.59
Span, exposed, at hinge line, in.	4.2
Mean geometric chord, in.	3.33
Ratio of exposed area to wing area	0.062
Section	Hexagonal
Vertical tail panel:	
Area, exposed, sq in.	23.46
Span, exposed, in.	5.1
Taper ratio	0.314
Aspect ratio	1.11
Sweep of leading edge, deg	60
Section	Wedge plate

TABLE II

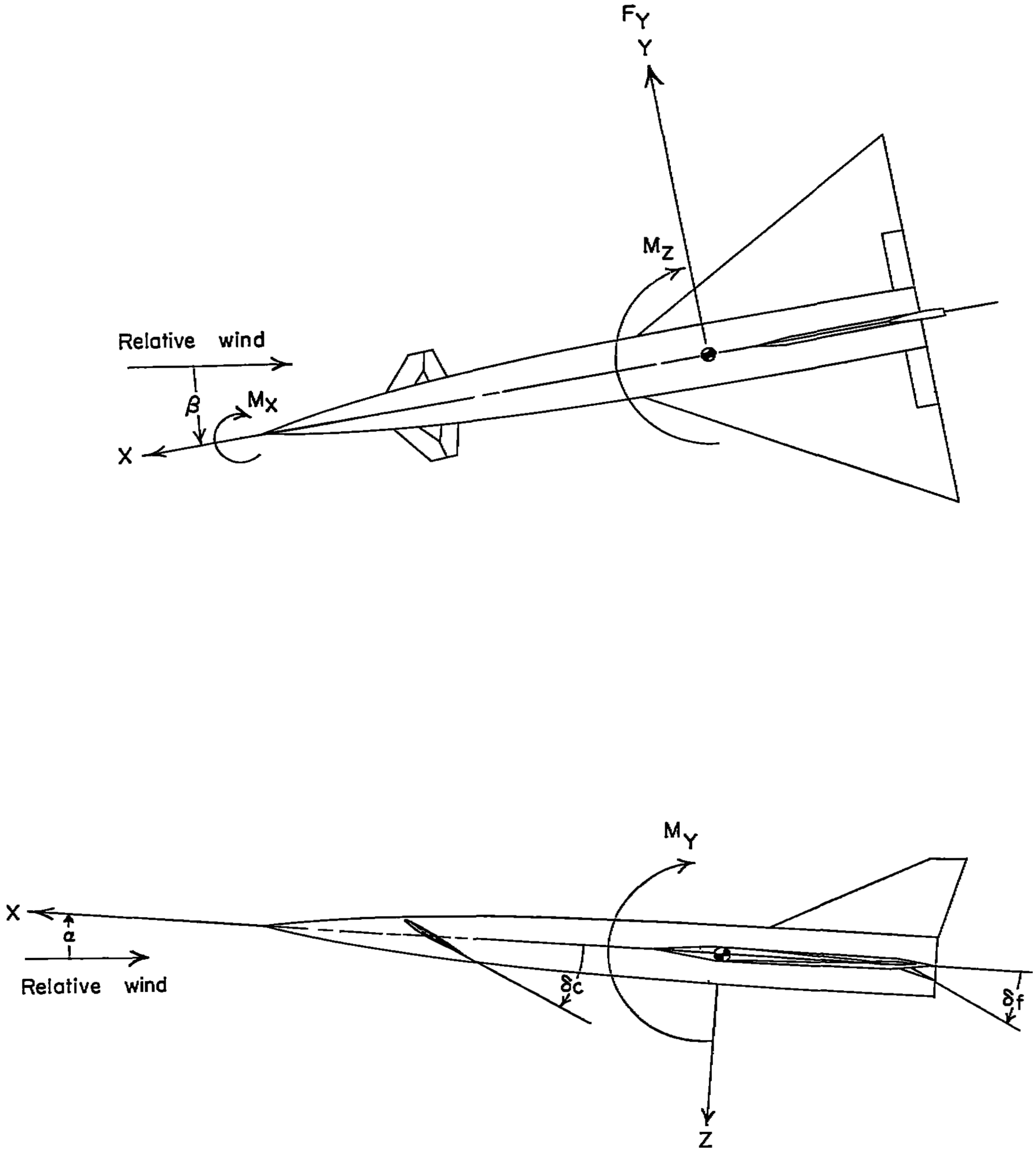
BODY COORDINATES

Body station, in.	Radius, in.
0	0
.297	.076
.627	.156
.956	.233
1.285	.307
1.615	.378
1.945	.445
2.275	.509
2.605	.573
2.936	.627
3.598	.682
3.929	.732
4.260	.780
4.592	.824
4.923	.865
5.255	.903
5.587	.940
5.920	.968
6.252	.996
6.583	1.020
18.648	1.042 } Conical section
37.000	1.75 }



(a) Stability axis.

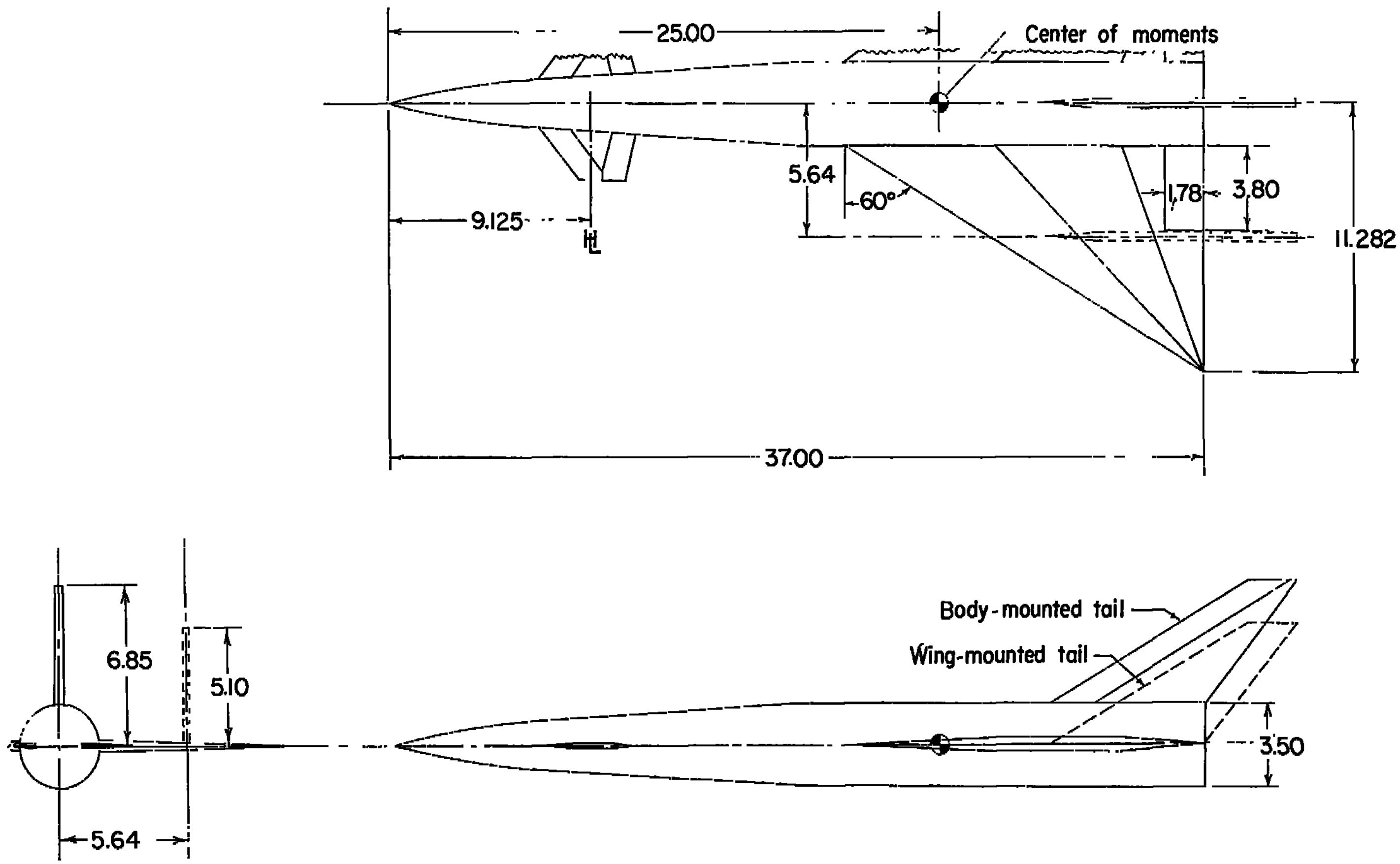
Figure 1.- Axis systems. (Arrows indicate positive directions.)



(b) Body axis.

Figure 1.- Concluded.

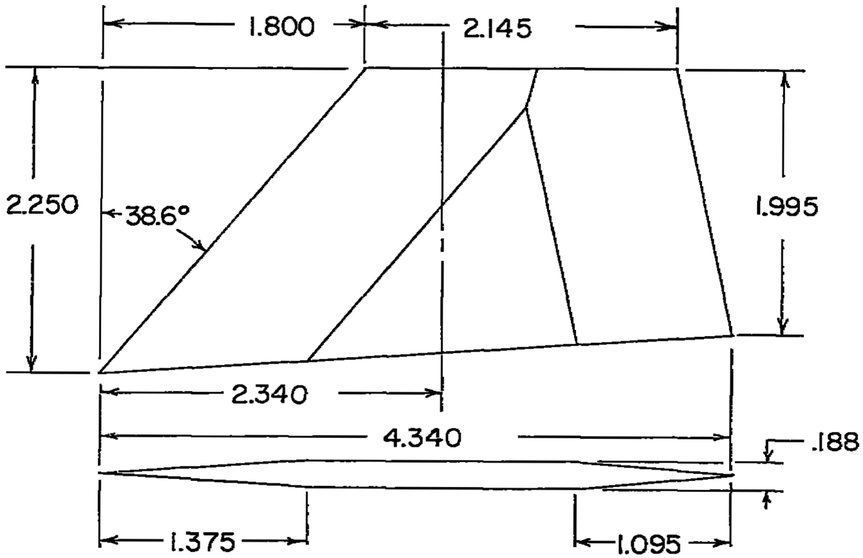
[redacted]



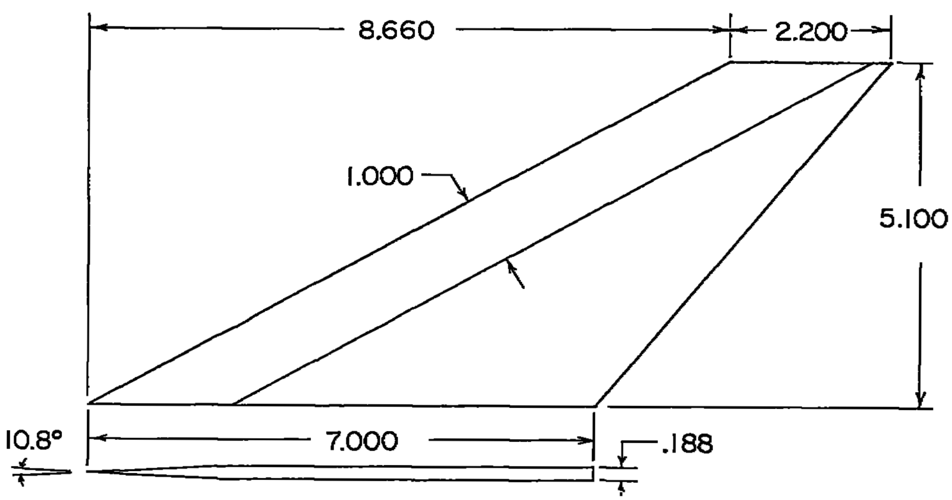
(a) Three-view drawing of general arrangement.

Figure 2.- Details of model.

[redacted]



Canard surface



Vertical tail

(b) Details of canard surface and vertical tail.

Figure 2.- Concluded.

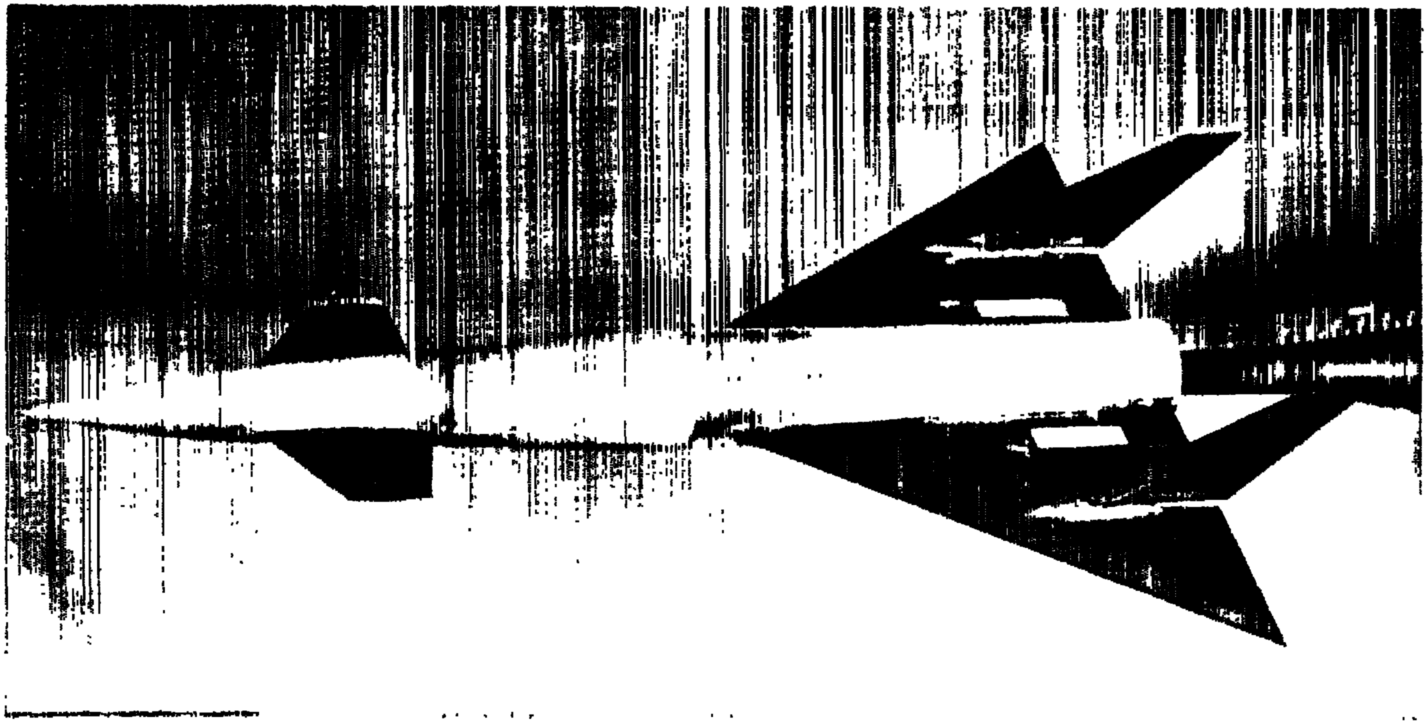
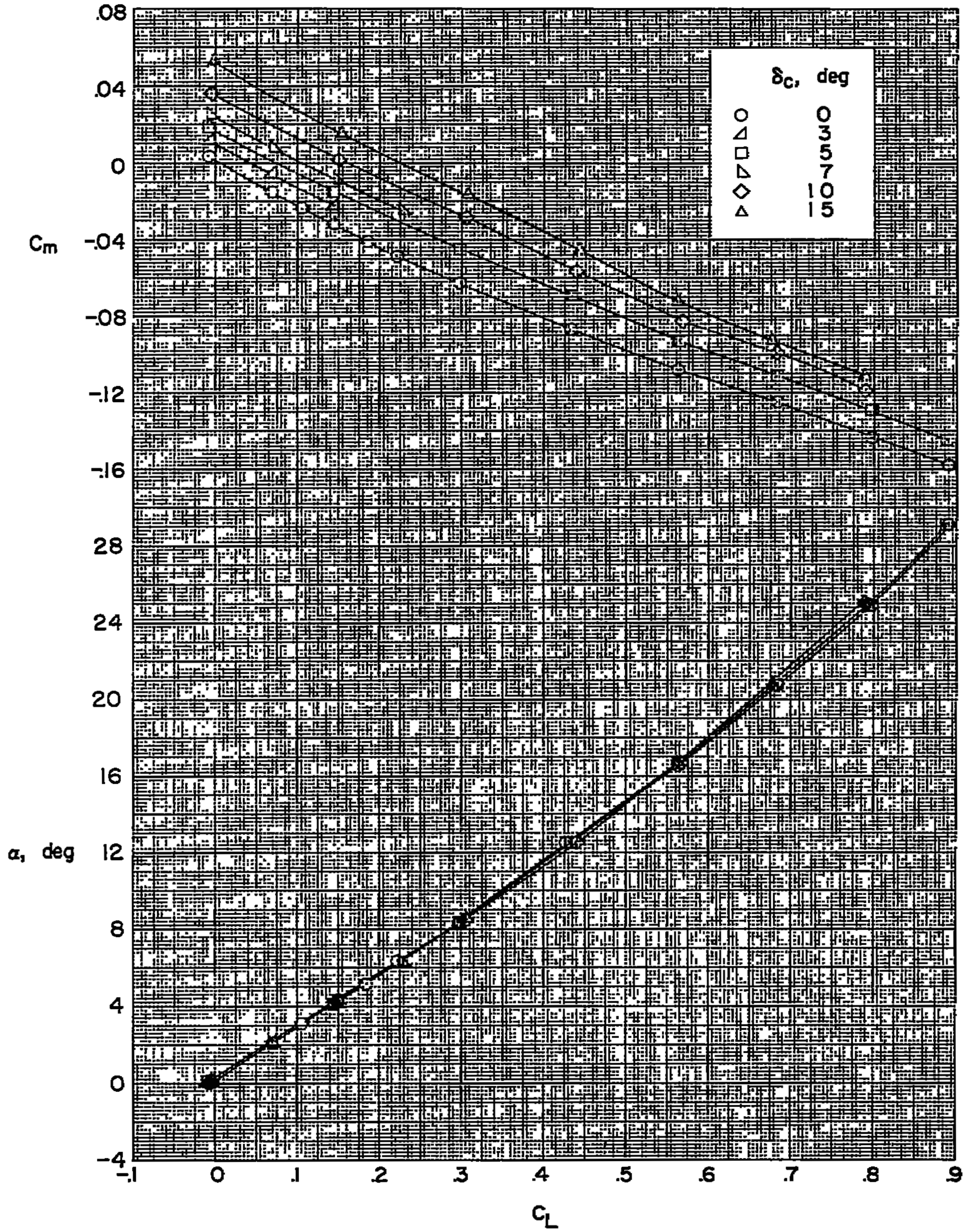
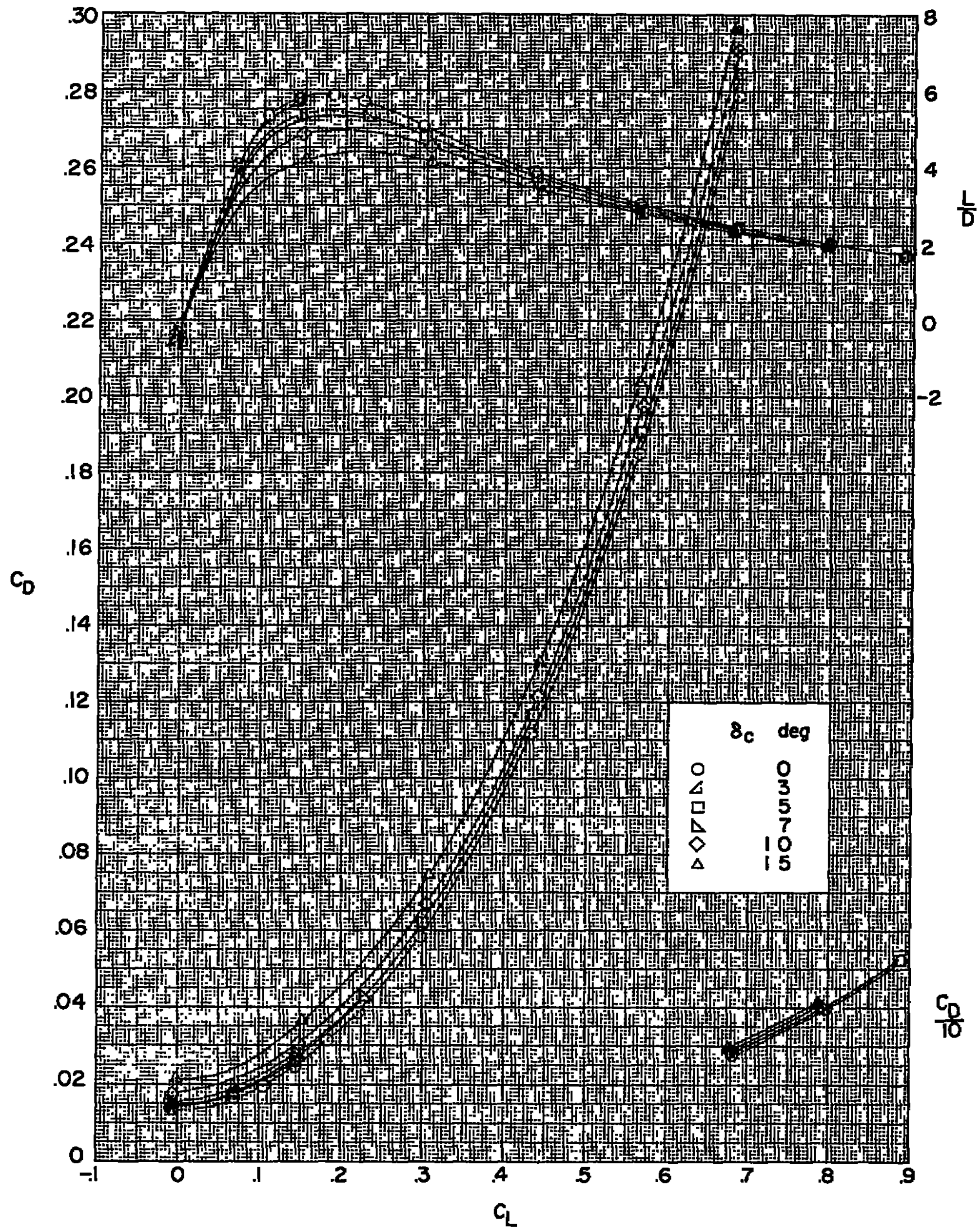


Figure 3.- Photograph of model.   L-57-890



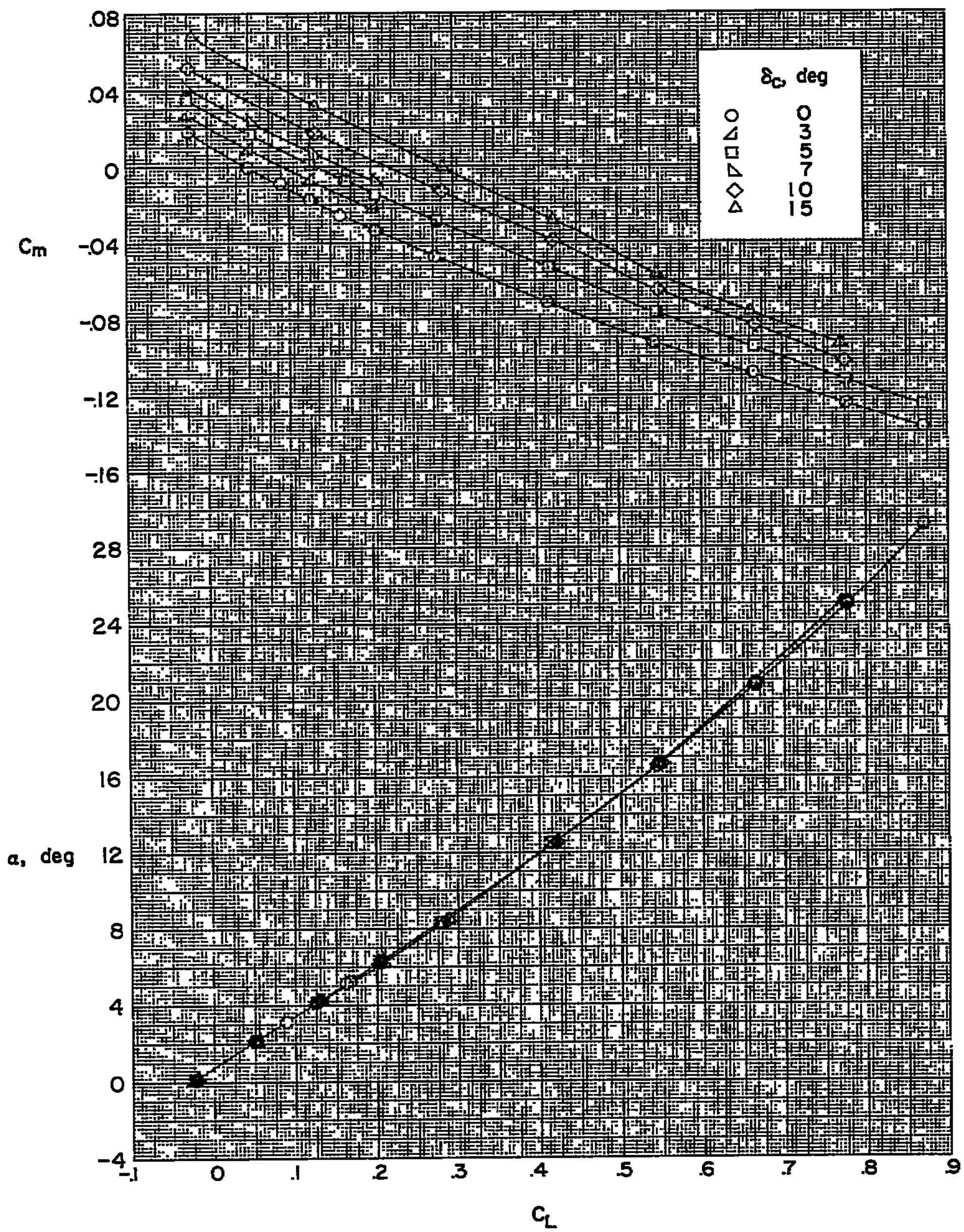
(a) $\delta_f = 0^{\circ}$.

Figure 4.- Effects of canard deflection on aerodynamic characteristics in pitch for various flap deflections. Single vertical tail.



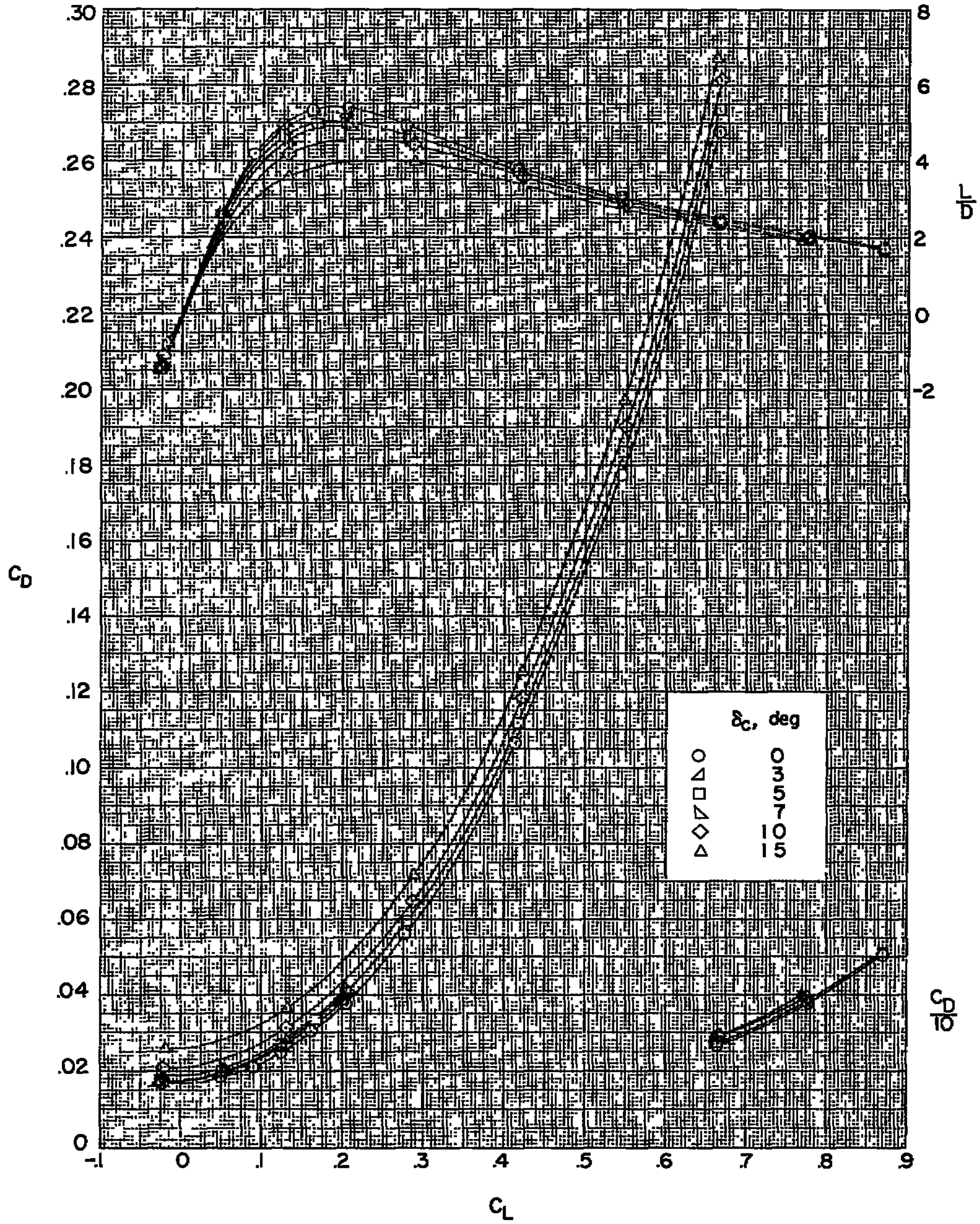
(a) Concluded.

Figure 4.- Continued.



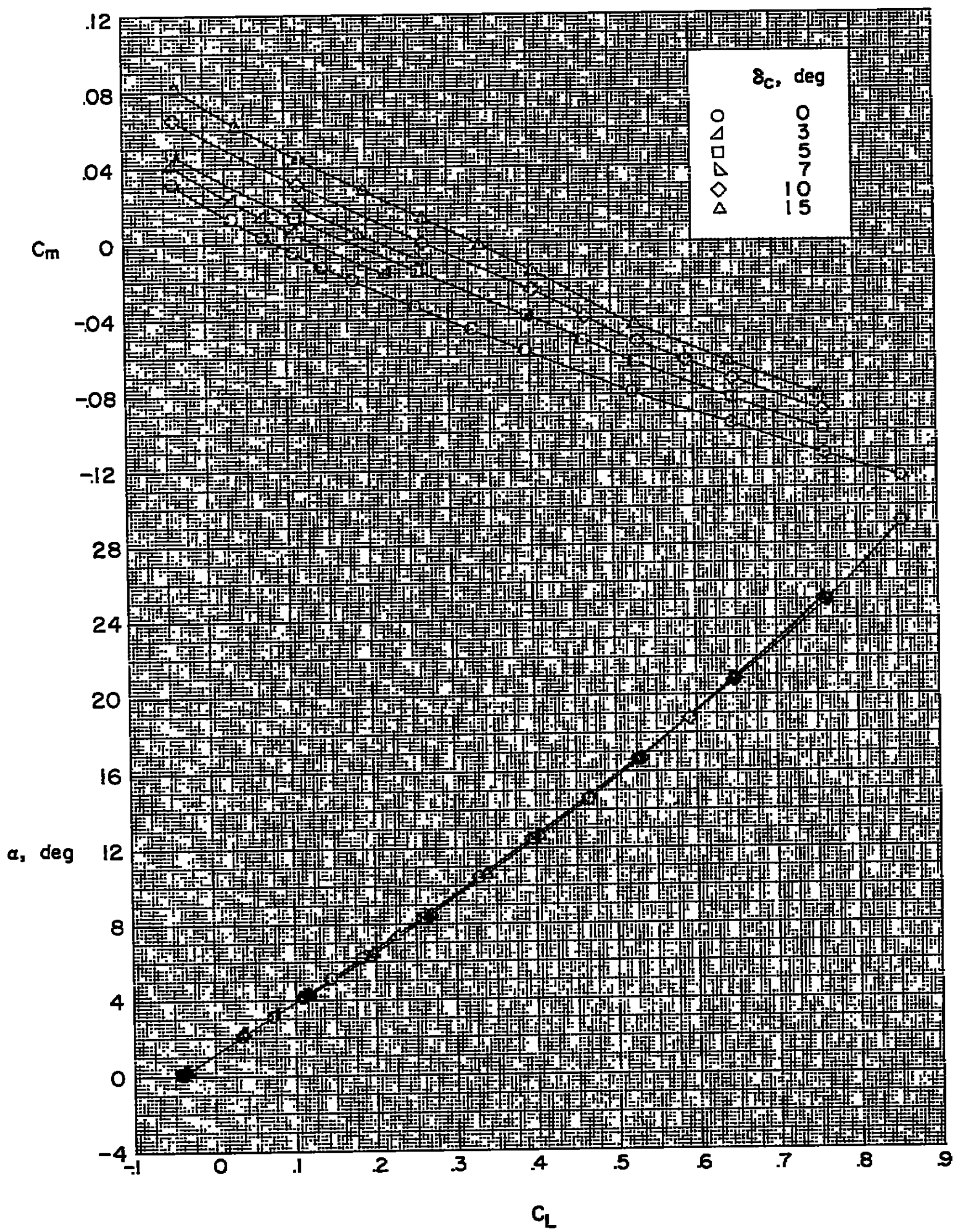
(b) $\delta_f = -10^{\circ}$.

Figure 4.- Continued.



(b) Concluded.

Figure 4.- Continued.



(c) $\delta_f = -20^{\circ}$.

Figure 4.- Continued.

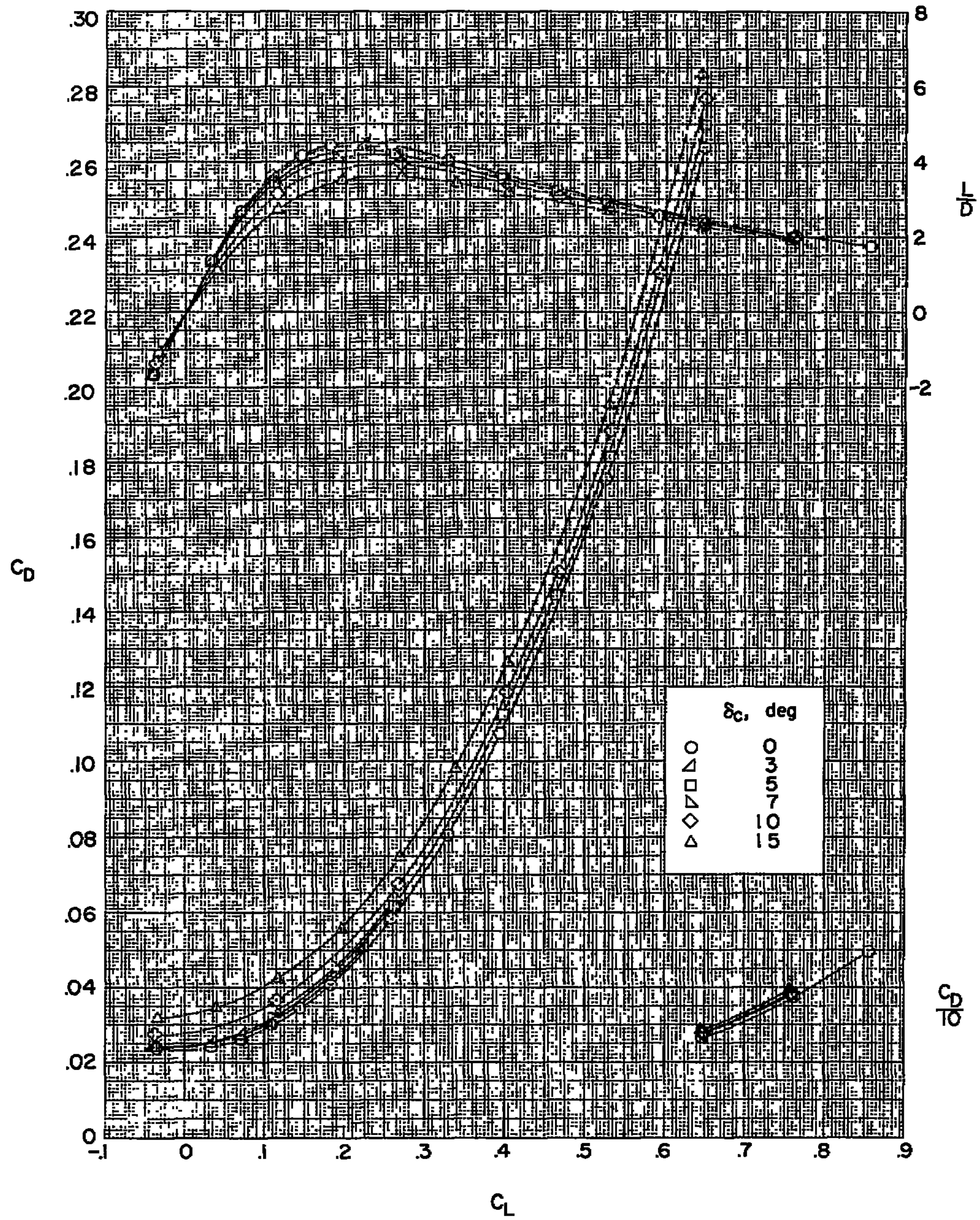


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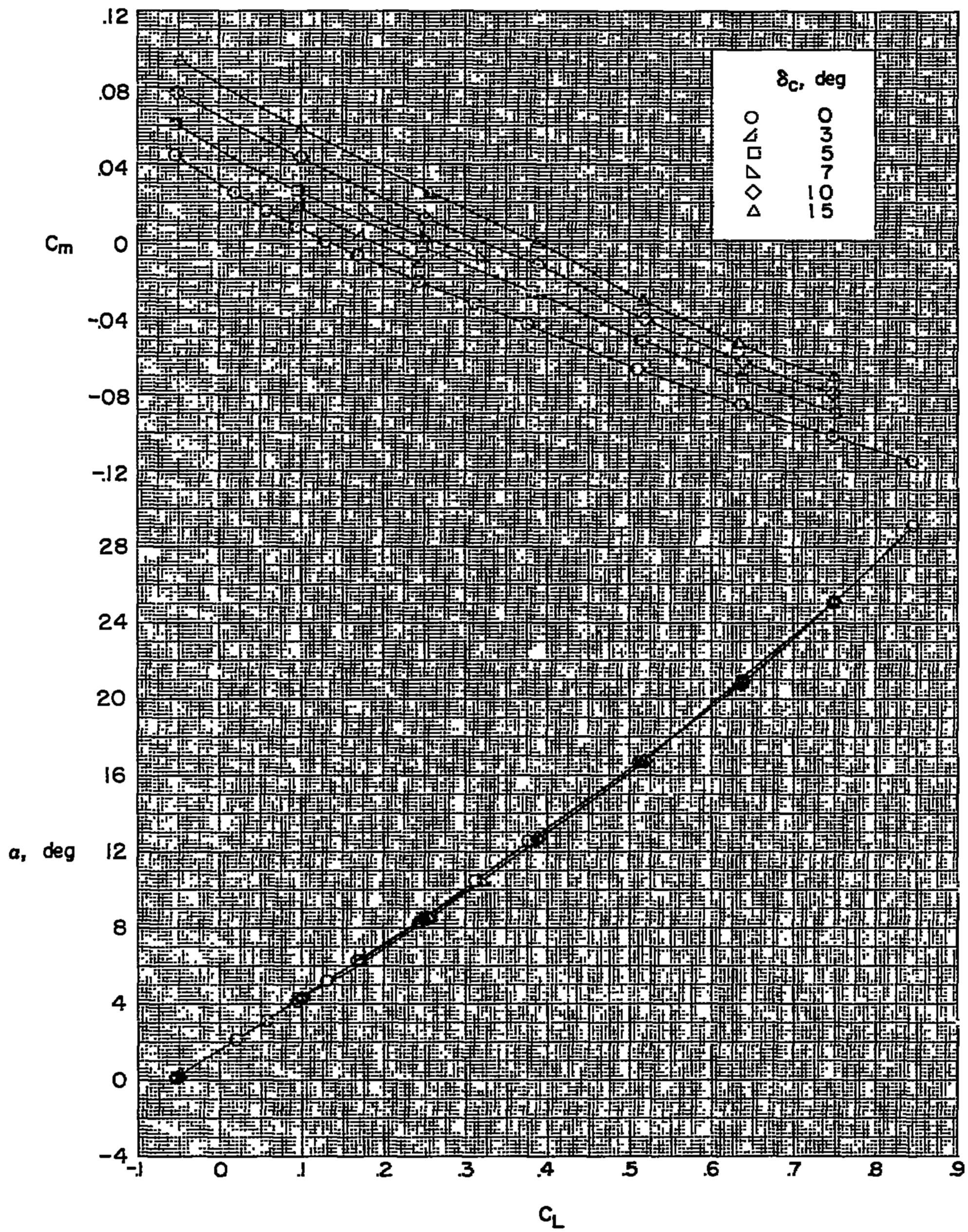
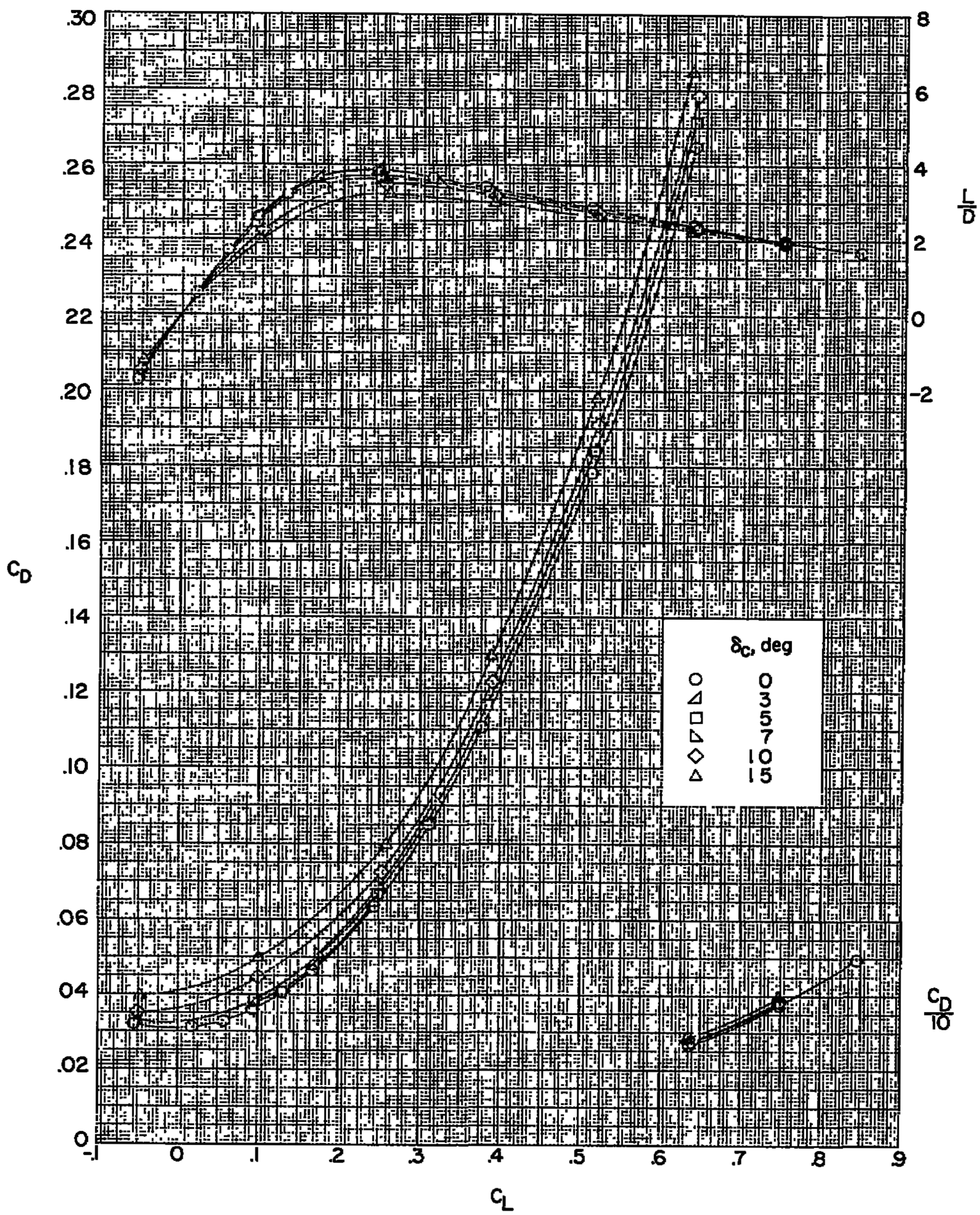
Figure 4.- Continued.



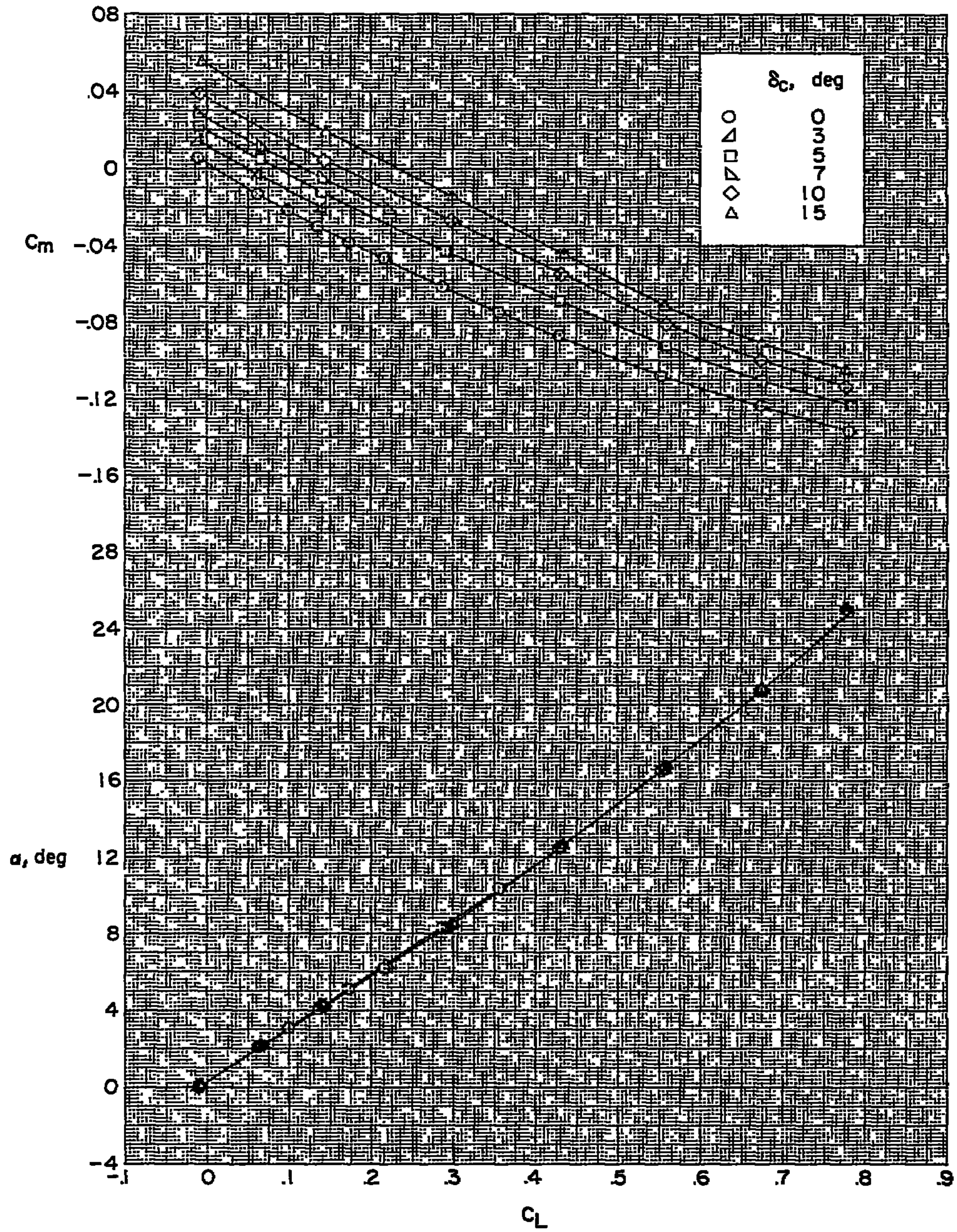
(d) $\delta_f = -30^{\circ}$.

Figure 4.- Continued.



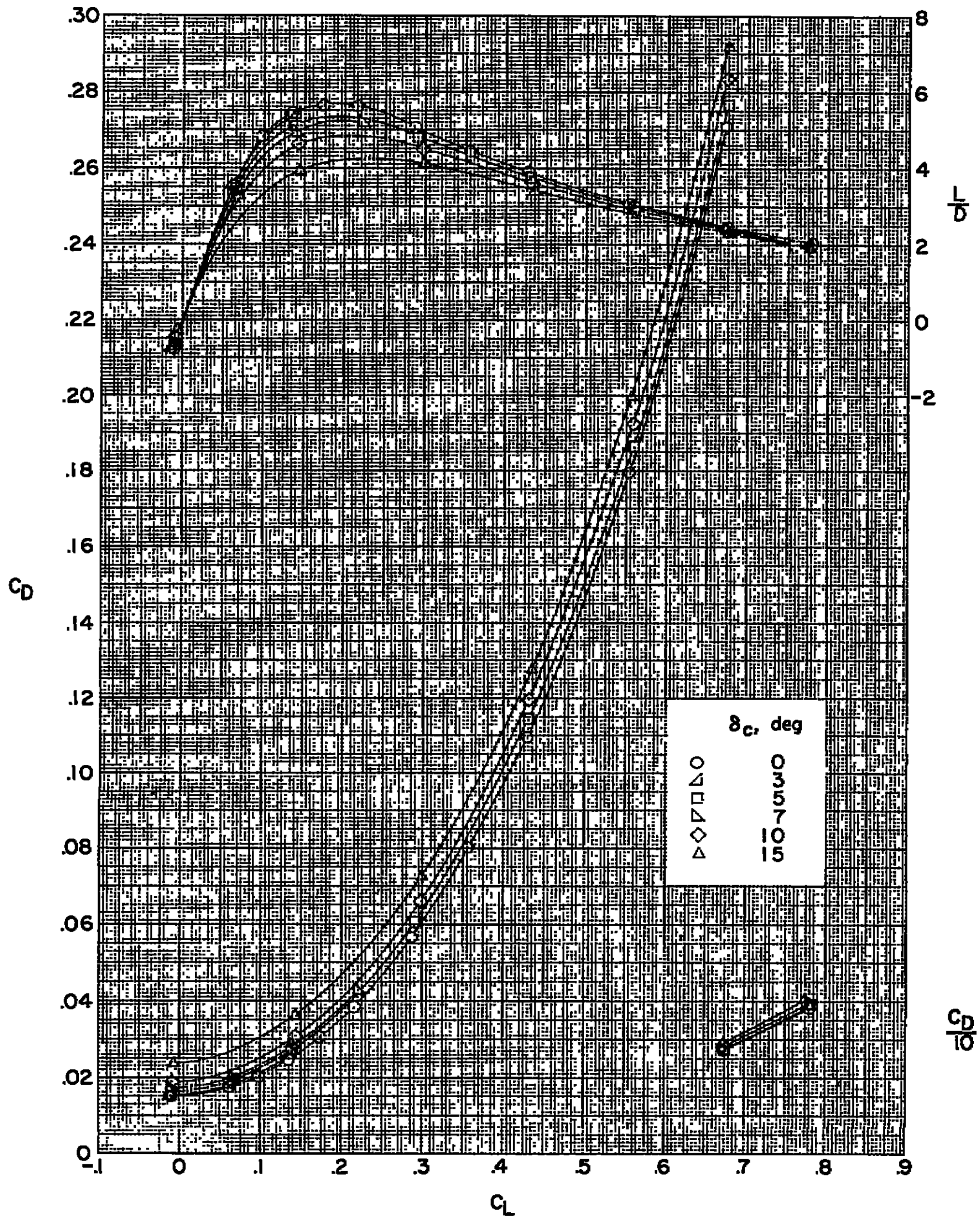
(d) Concluded.

Figure 4.- Concluded.



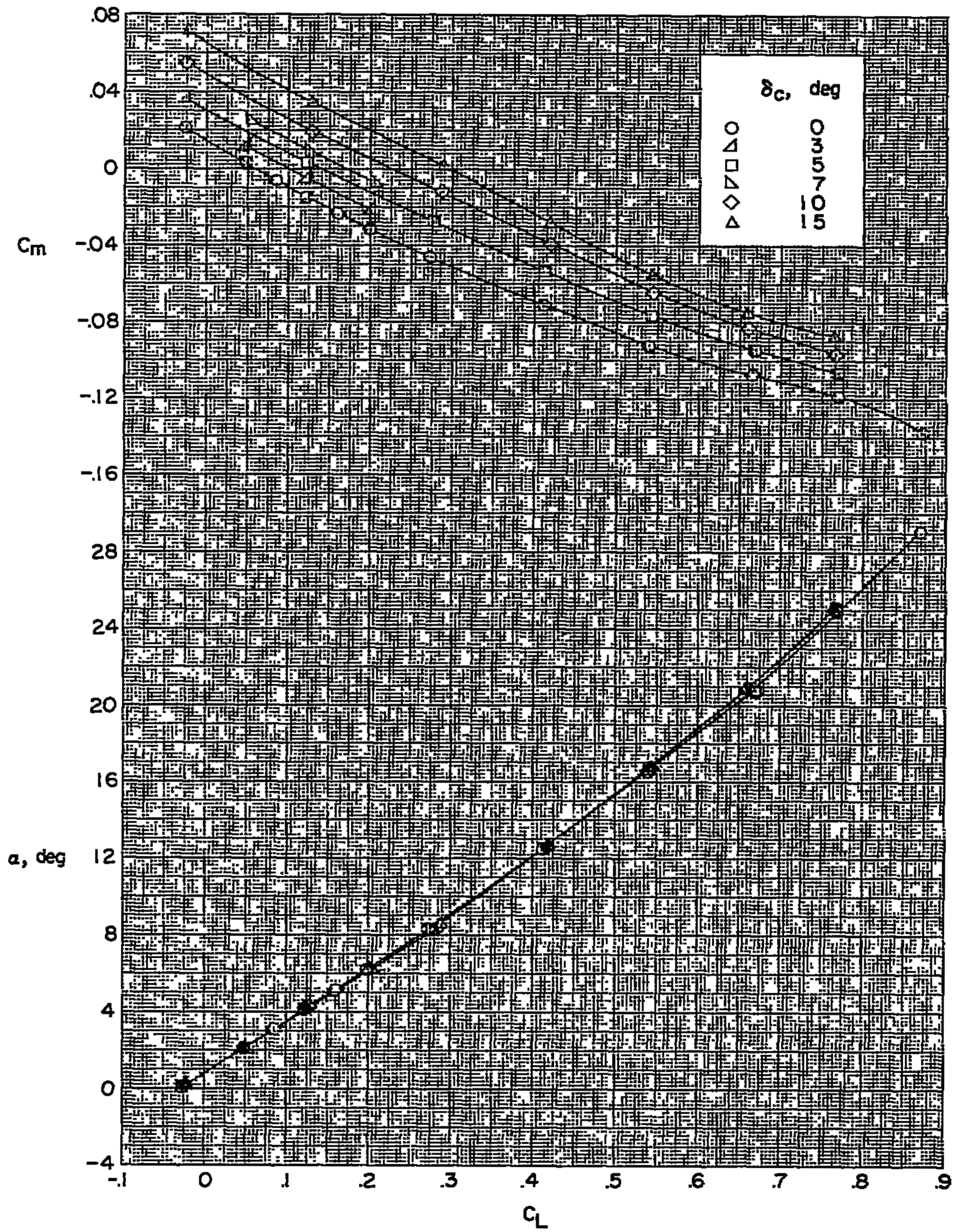
(a) $\delta_f = 0^{\circ}$.

Figure 5.- Effects of canard deflection on aerodynamic characteristics in pitch for various flap deflections. Twin vertical tails.



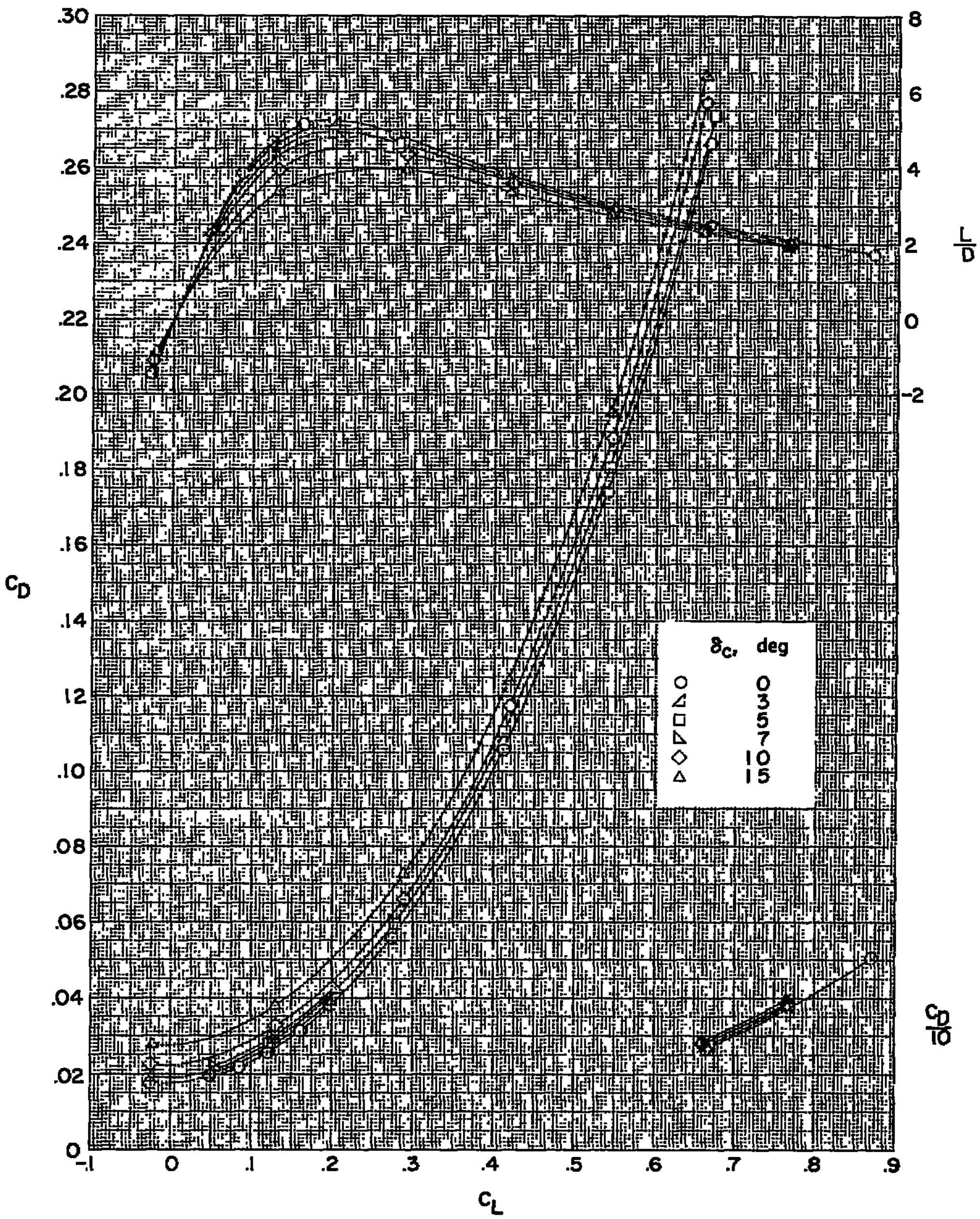
(a) Concluded.

Figure 5.- Continued.



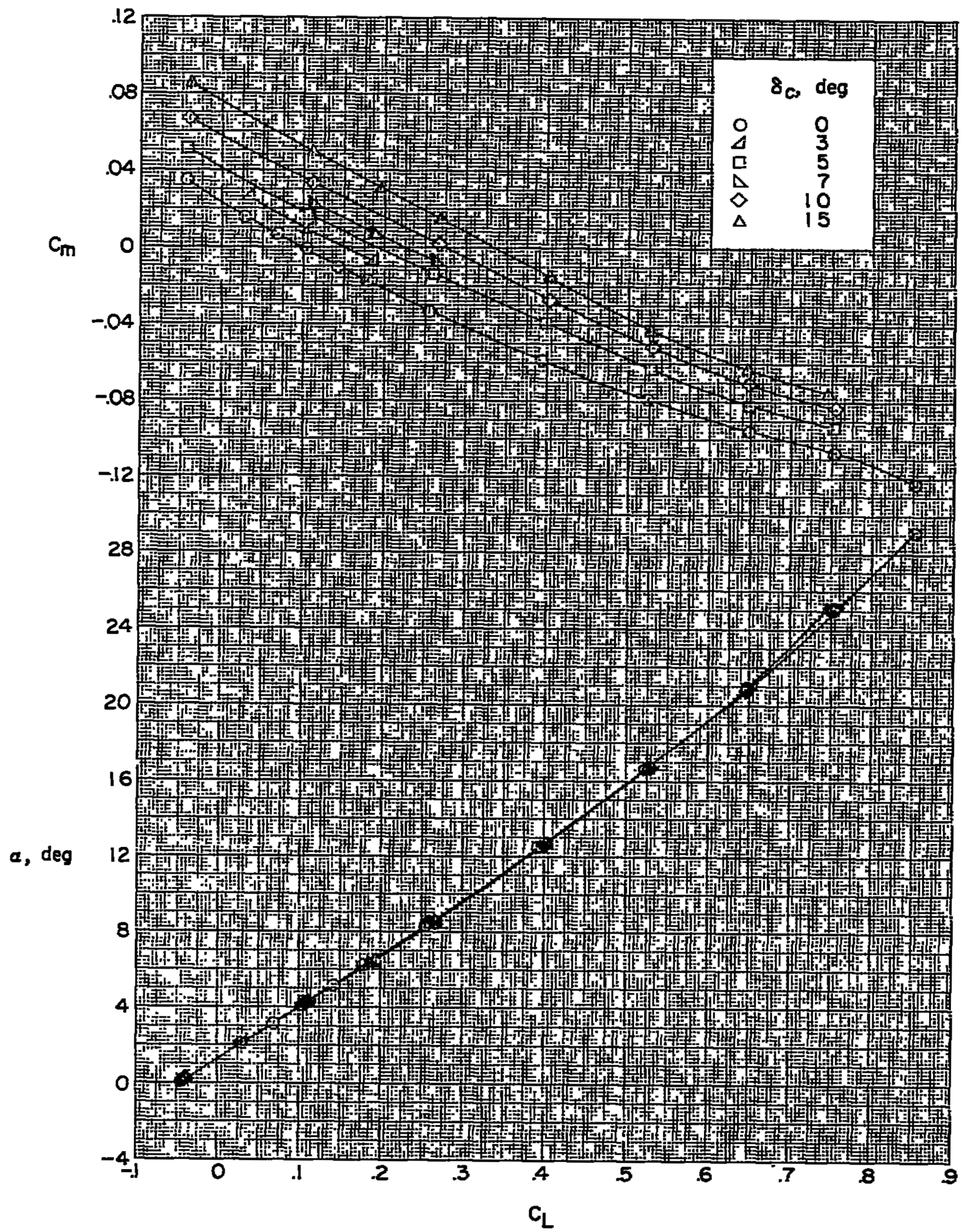
(b) $\delta_f = -10^{\circ}$.

Figure 5.- Continued.



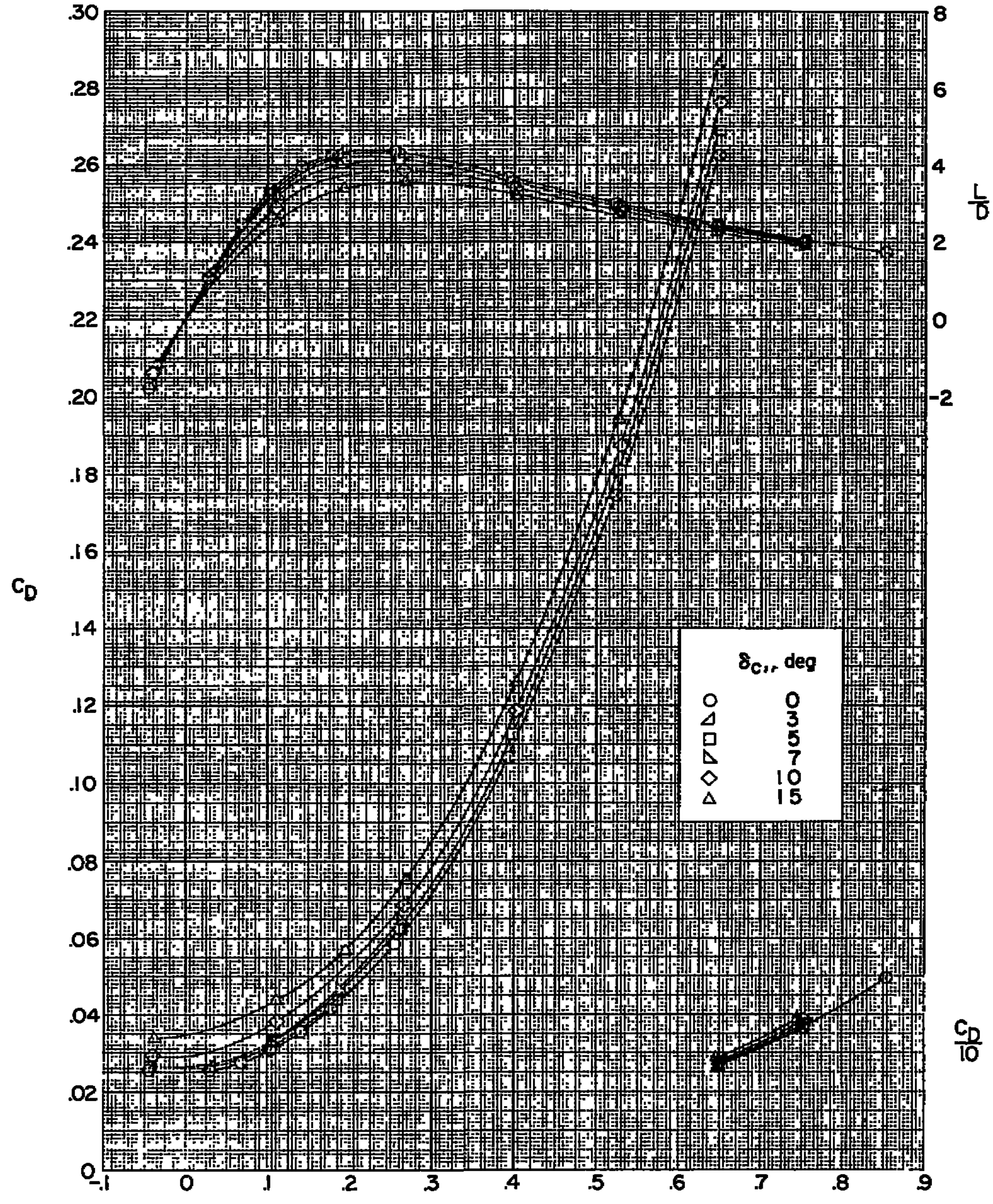
(b) Concluded.

Figure 5.- Continued.



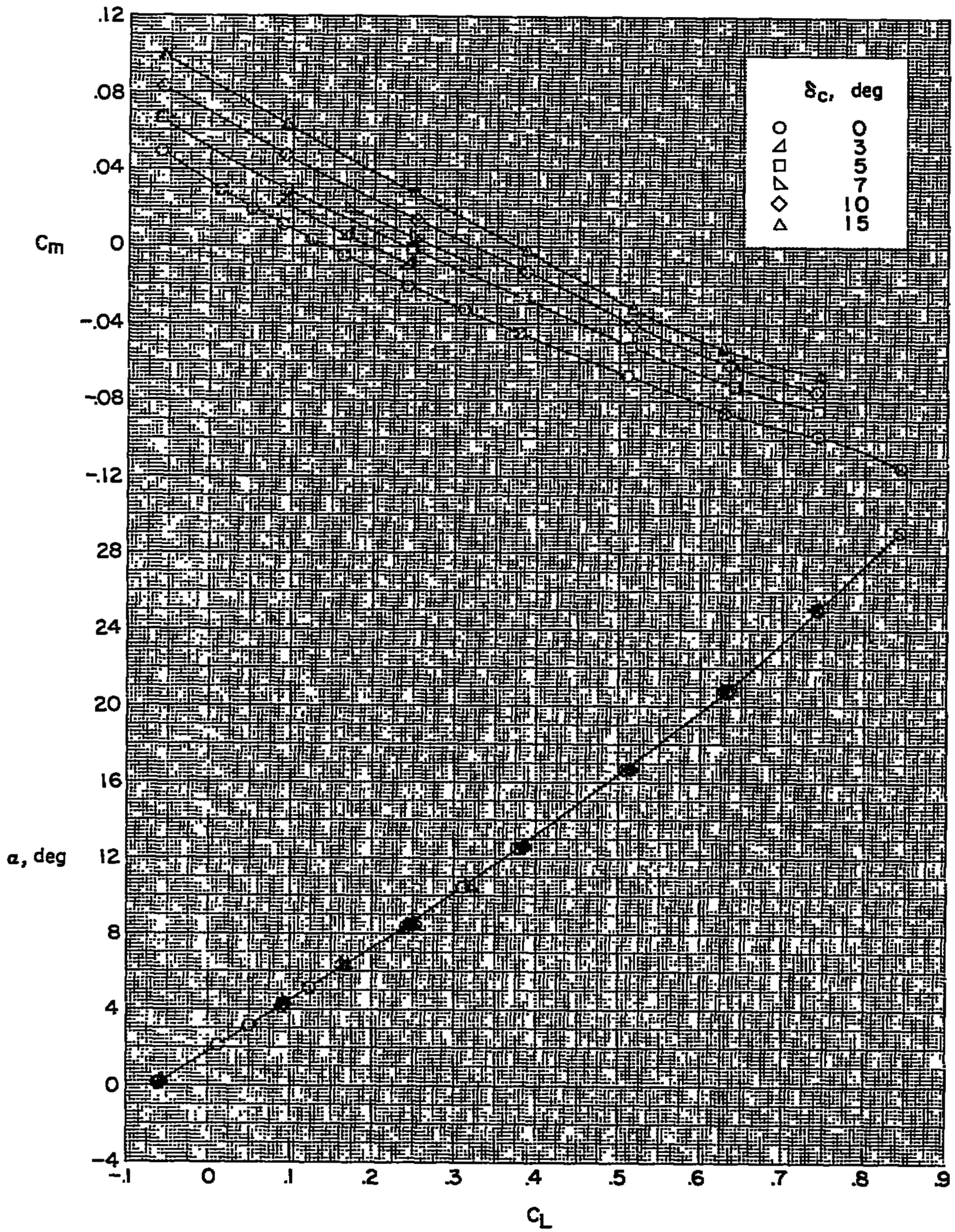
(c) $\delta_f = -20^{\circ}$.

Figure 5.- Continued.



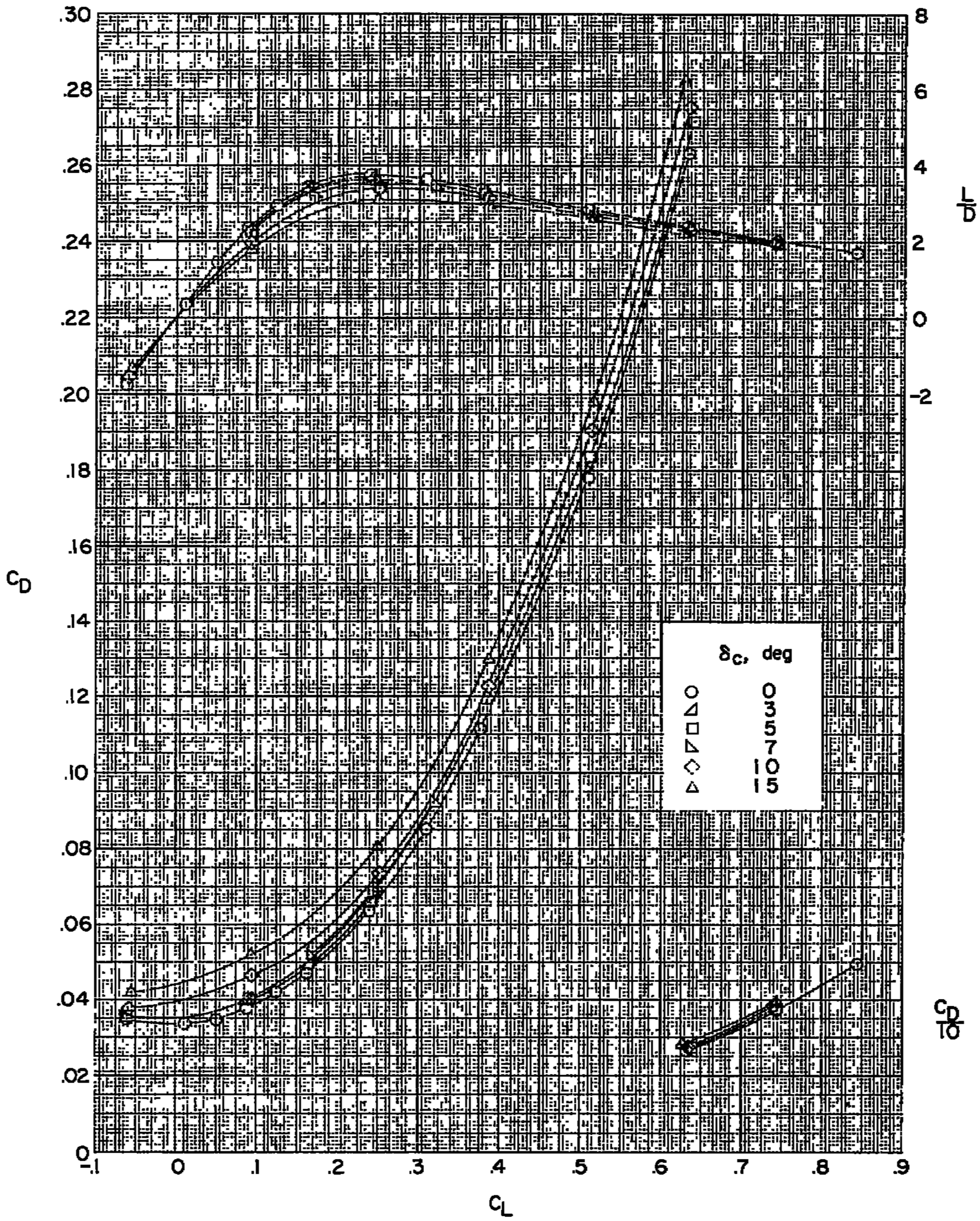
(c) Concluded.

Figure 5.- Continued.



(d) $\delta_f = -30^\circ$.

Figure 5.- Continued.



(d) Concluded.

Figure 5.- Concluded.

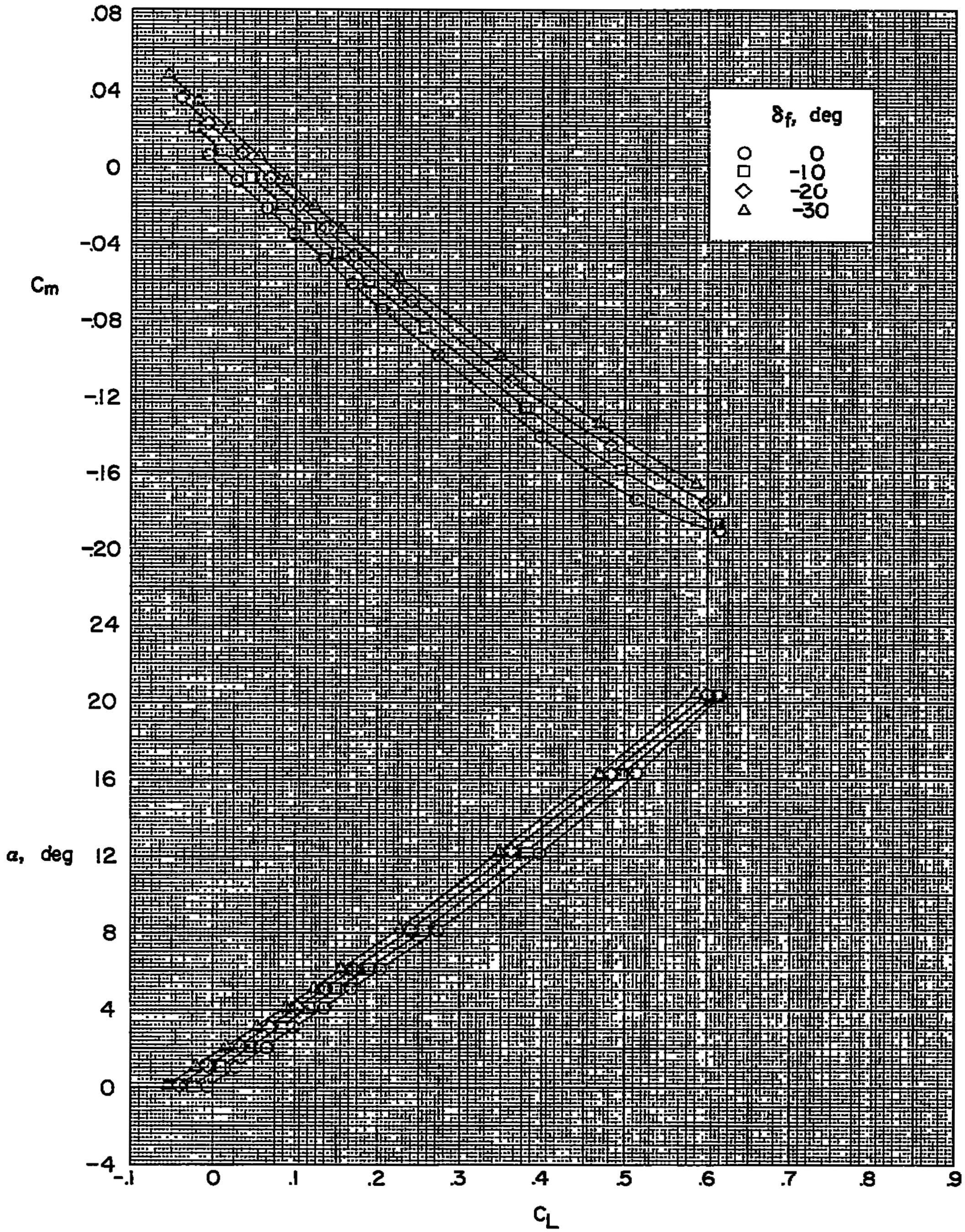


Figure 6.- Effects of trailing-edge flap deflection on aerodynamic characteristics in pitch. Canard off; single vertical tail.

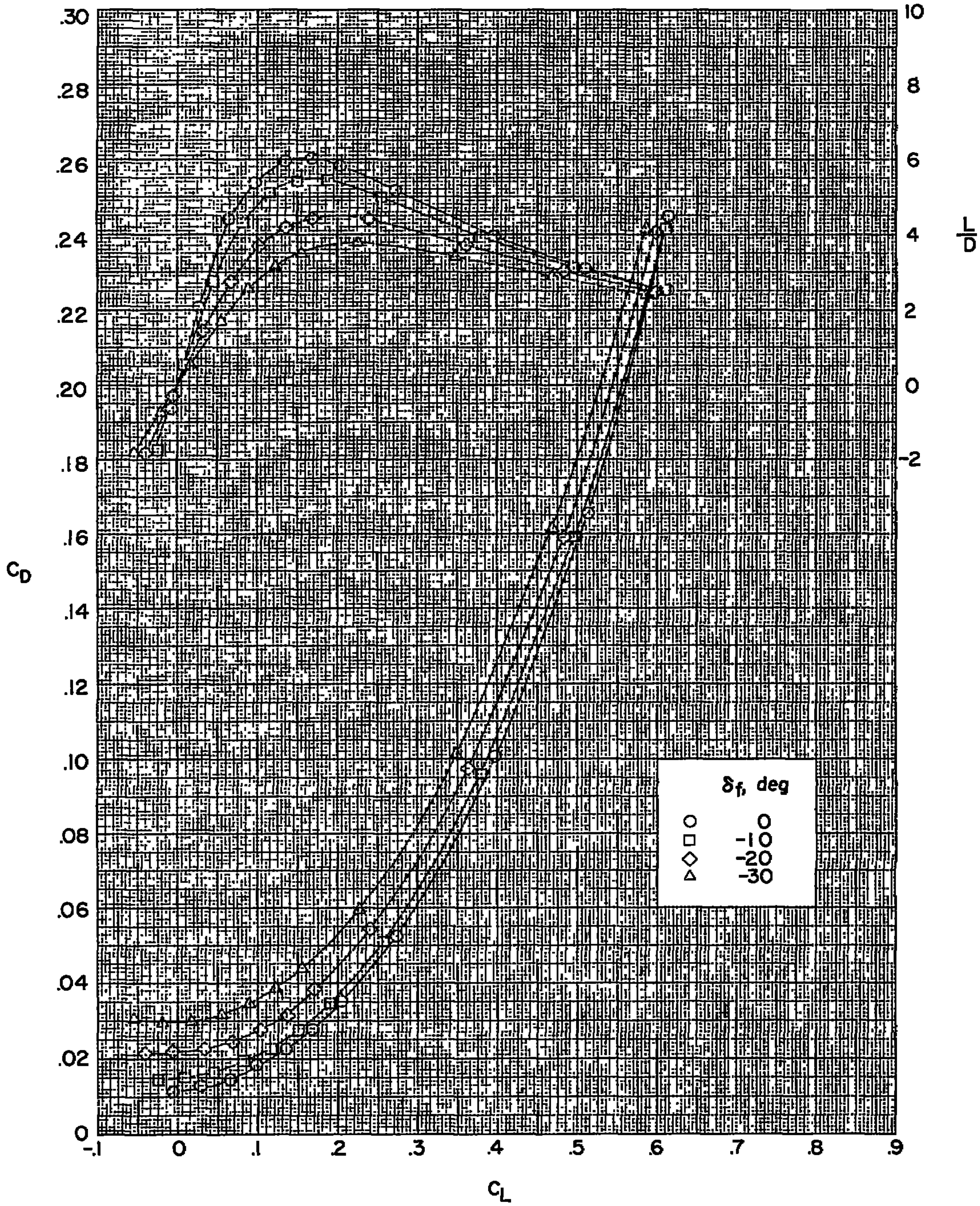


Figure 6.- Concluded.

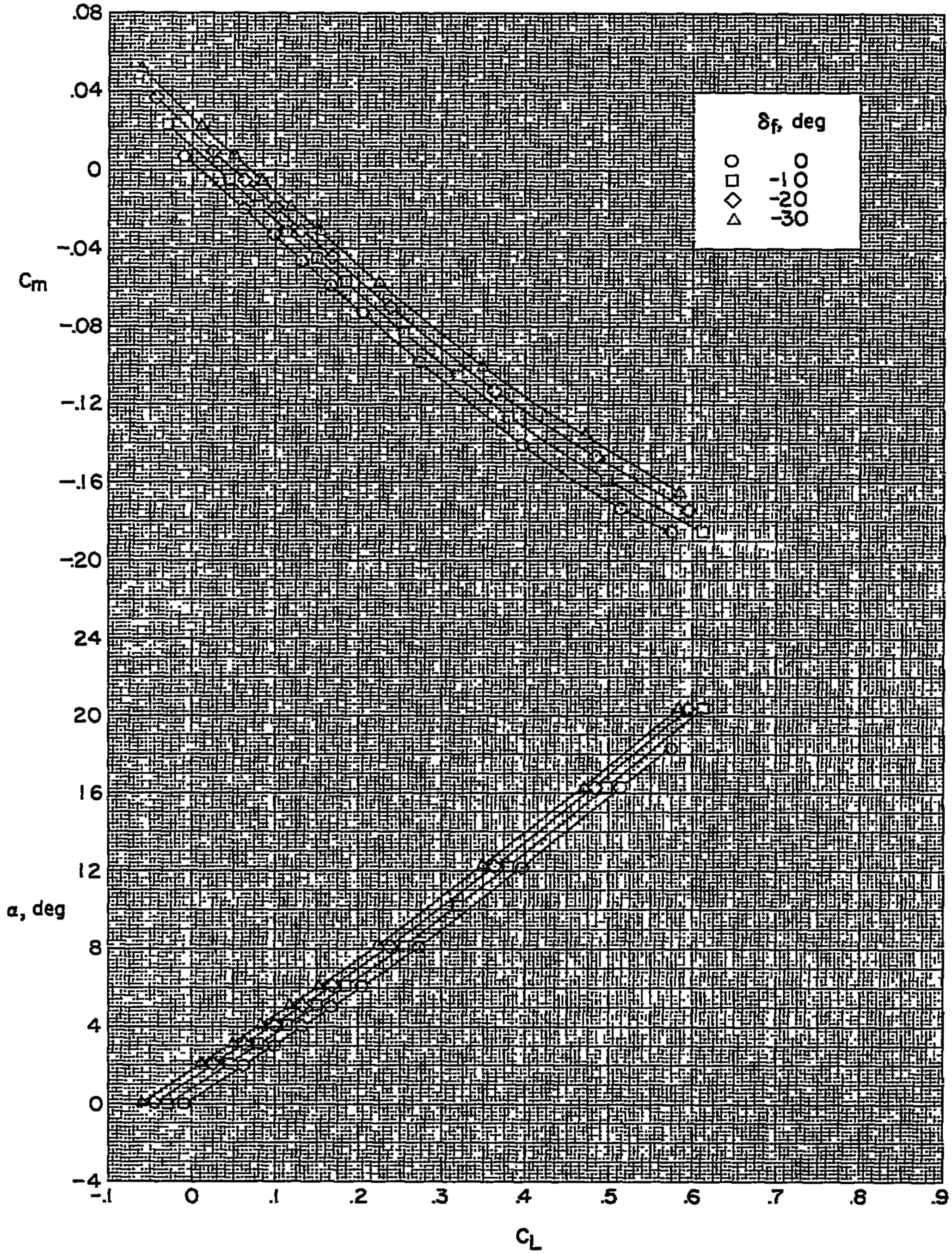


Figure 7.- Effects of trailing-edge flap deflection on aerodynamic characteristics in pitch. Canard off; twin vertical tails.

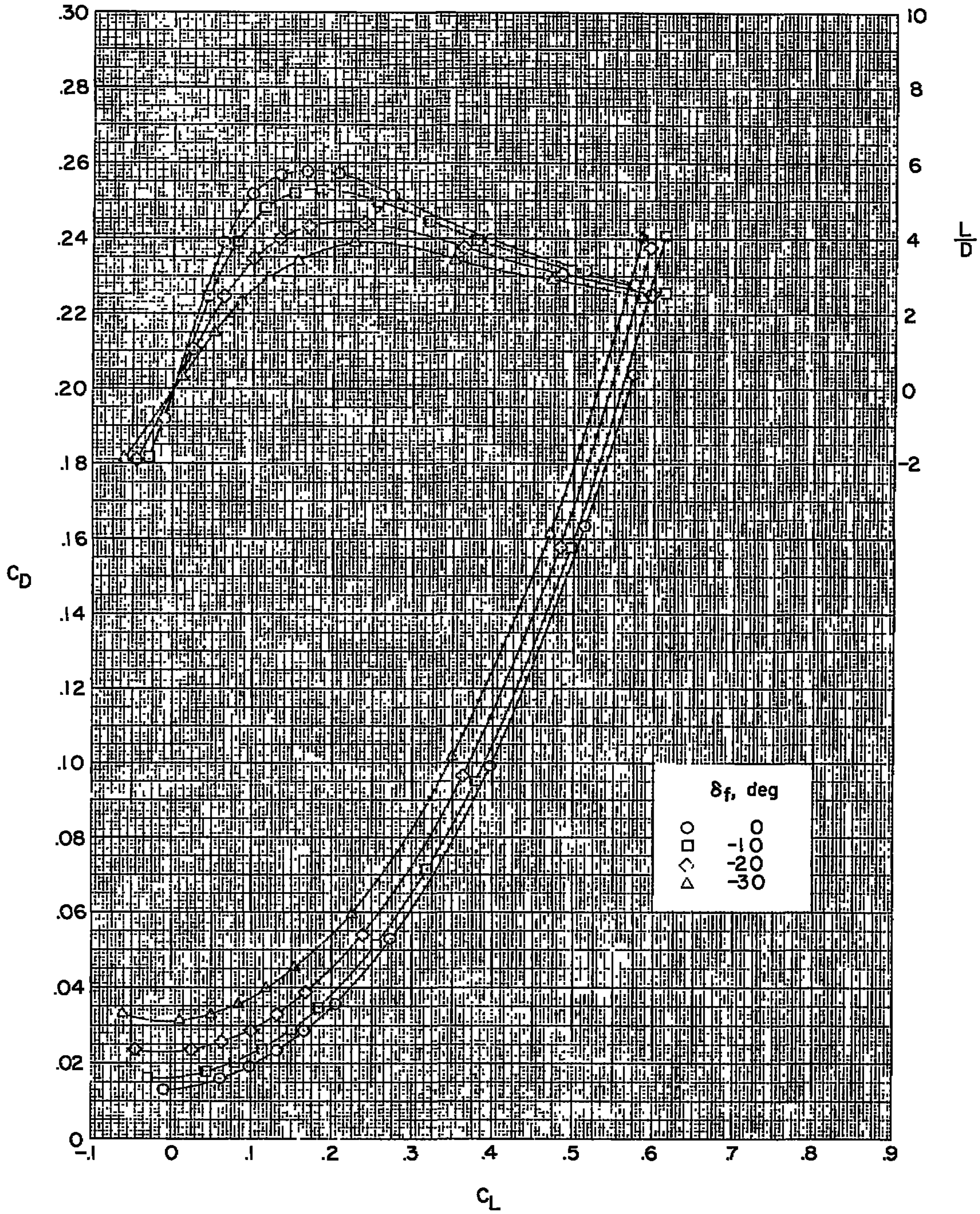
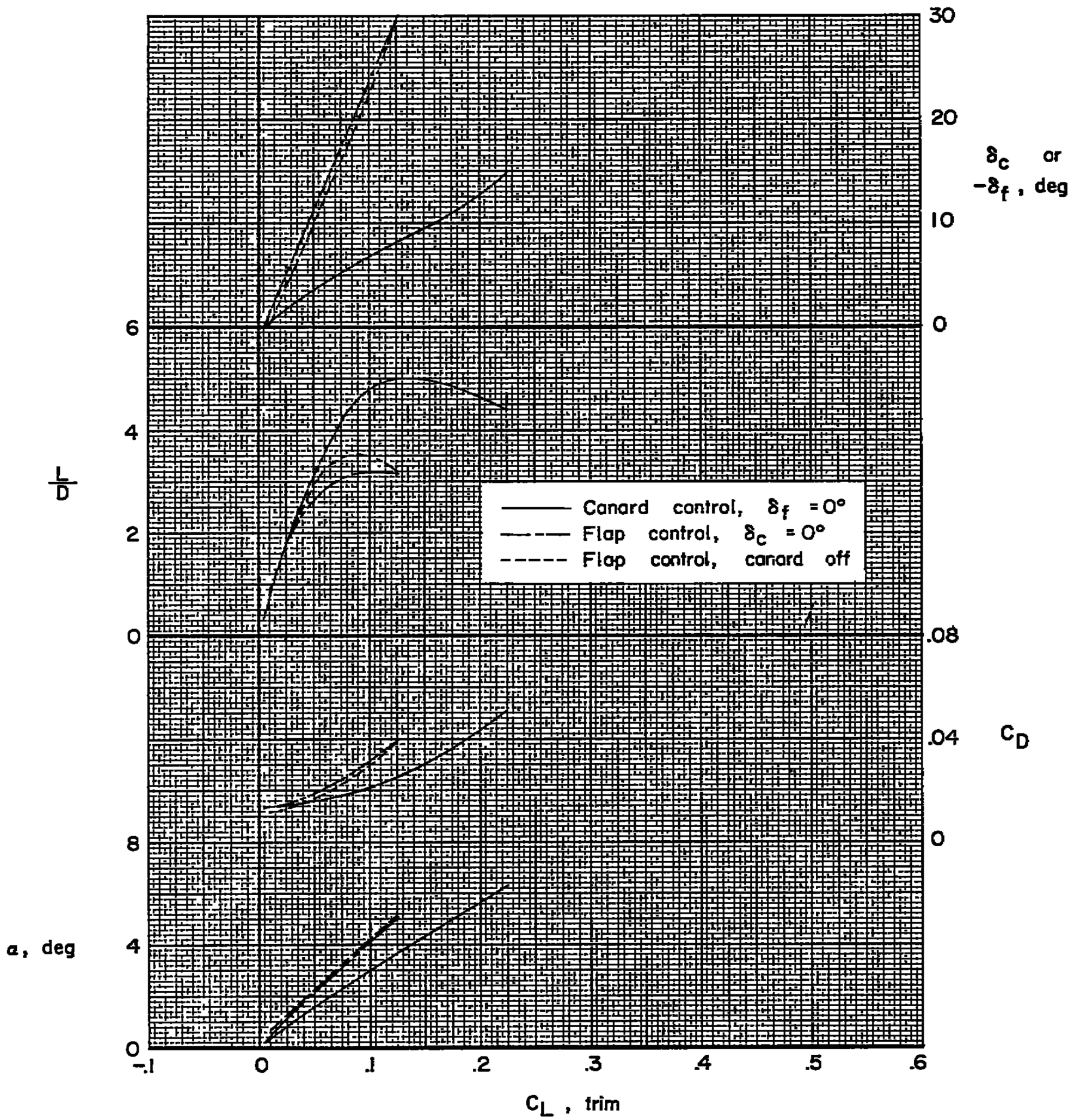
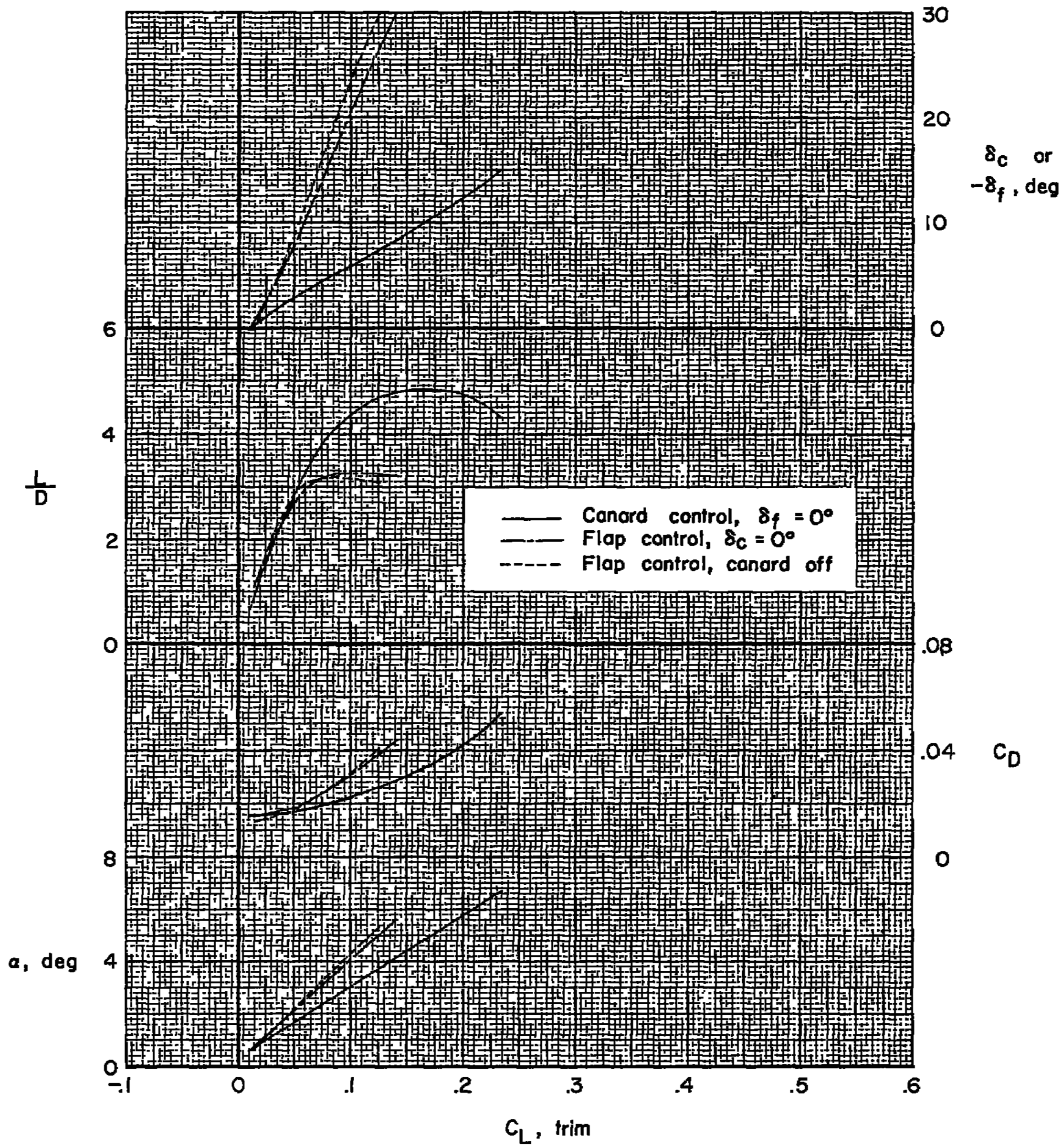


Figure 7.- Concluded.



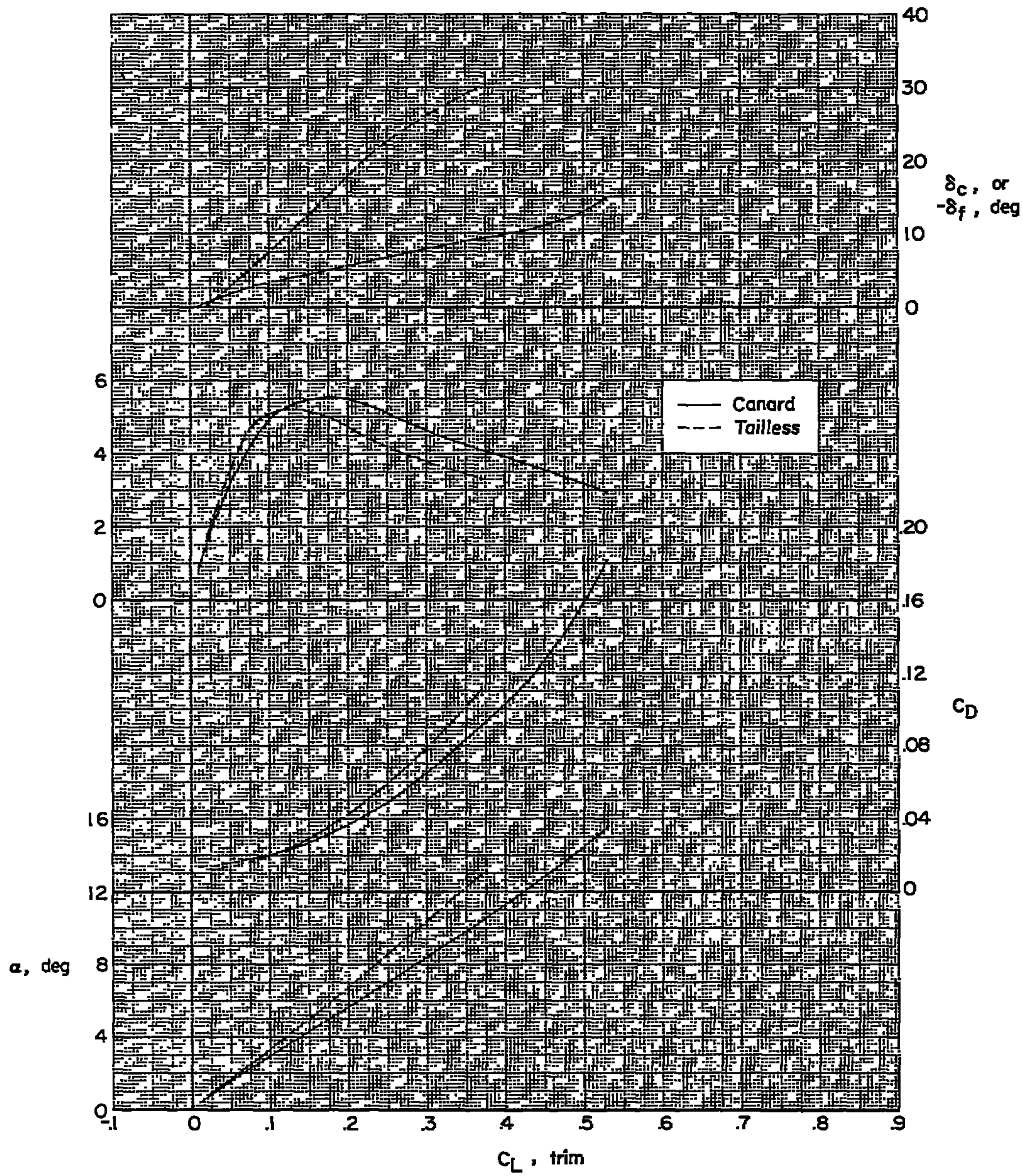
(a) Single vertical tail.

Figure 8.- Comparison of longitudinal trim characteristics with canard control and flap control for model with single and twin vertical tails. Static margin, approximately 22 percent $\bar{c}$.



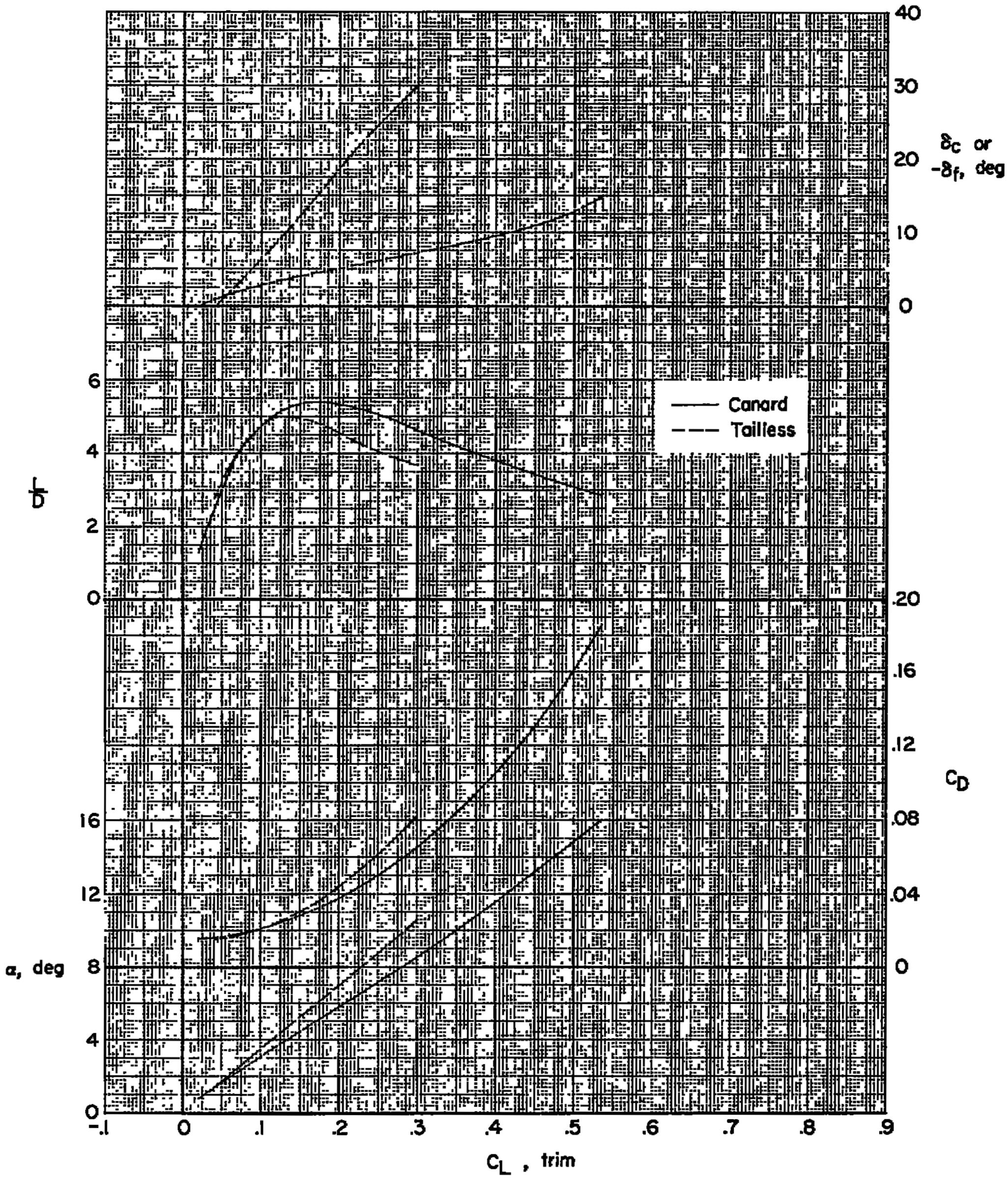
(b) Twin vertical tails.

Figure 8.- Concluded.



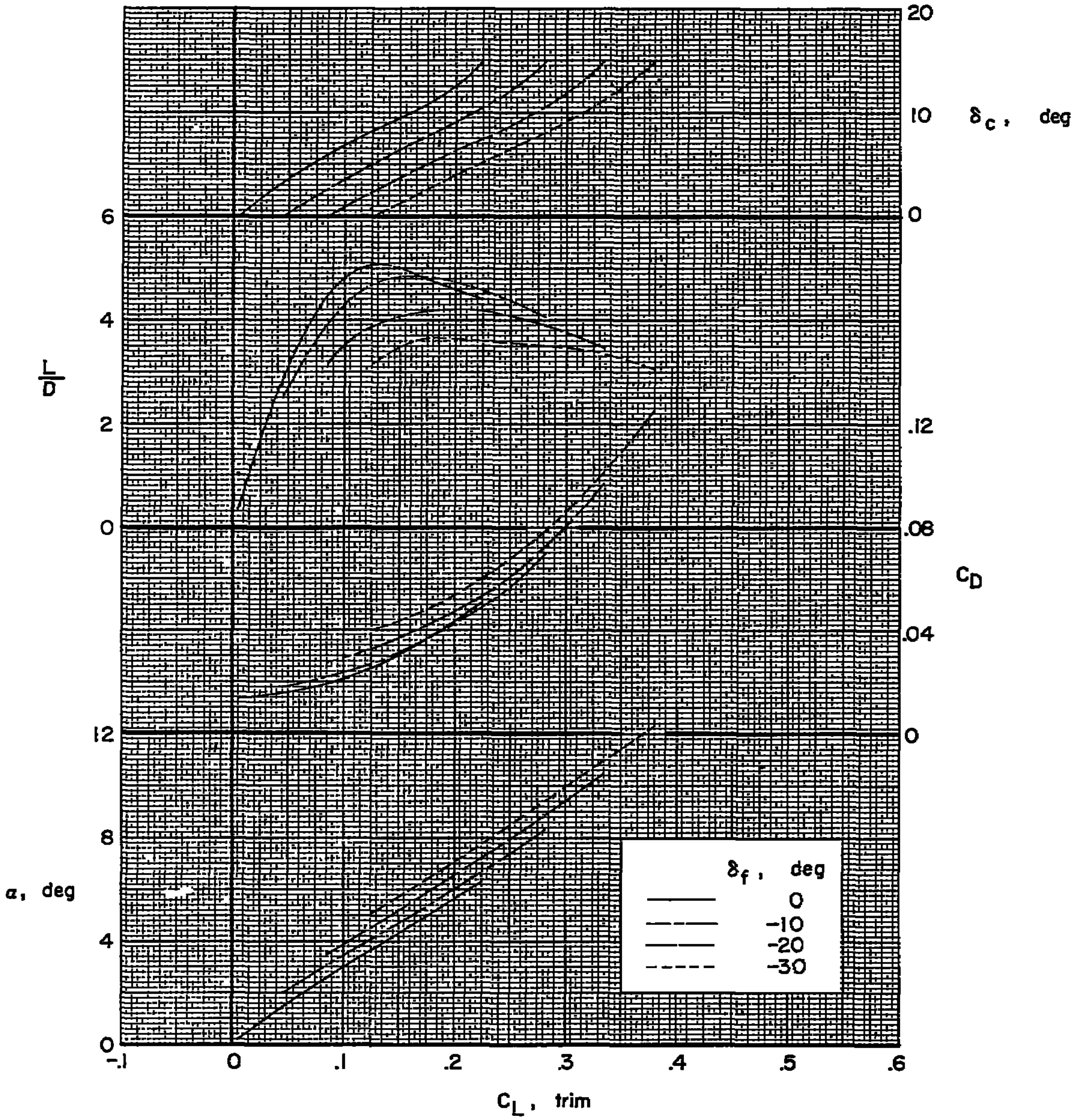
(a) Single vertical tail.

Figure 9.- Comparison of longitudinal trim characteristics for canard and tailless (canard off) configurations for single- and twin-vertical-tail arrangements. Static margin, approximately 10 percent $\bar{c}$.



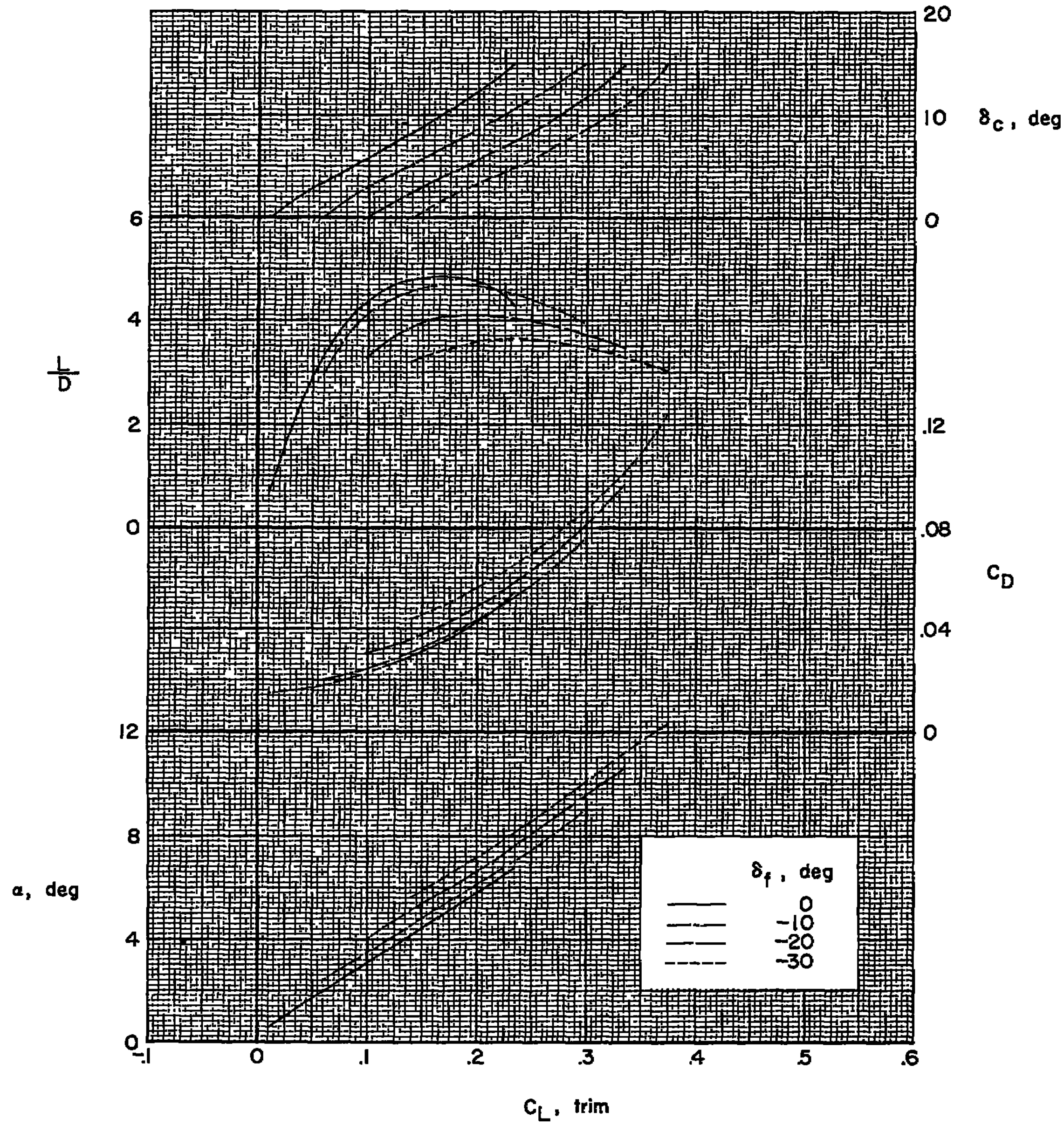
(b) Twin vertical tails.

Figure 9.- Concluded.



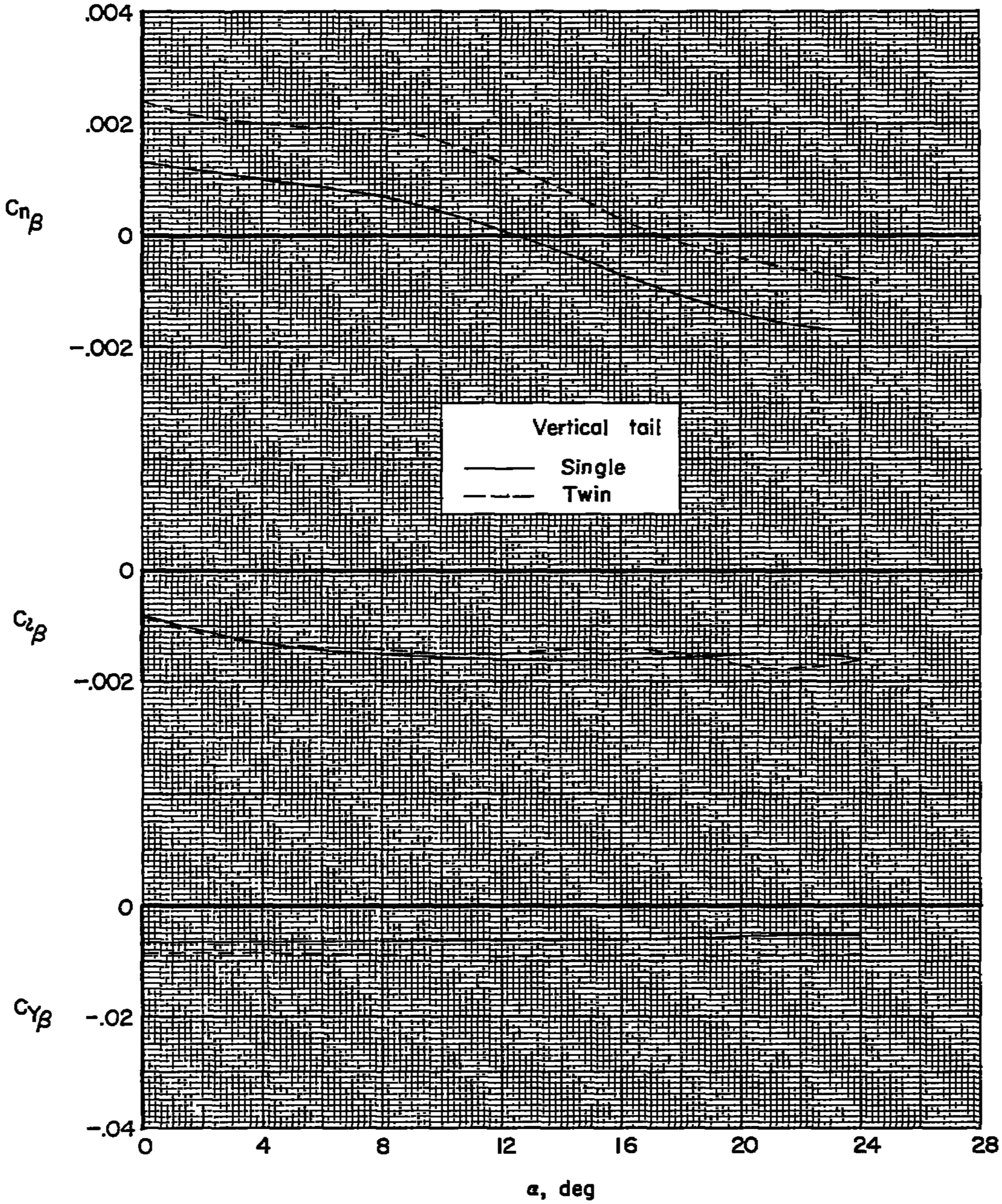
(a) Single vertical tail.

Figure 10.- Effect of canard deflection with various flap deflections on the longitudinal trim characteristics of the model with single and twin vertical tails. Static margin, approximately 22 percent $\bar{c}$.



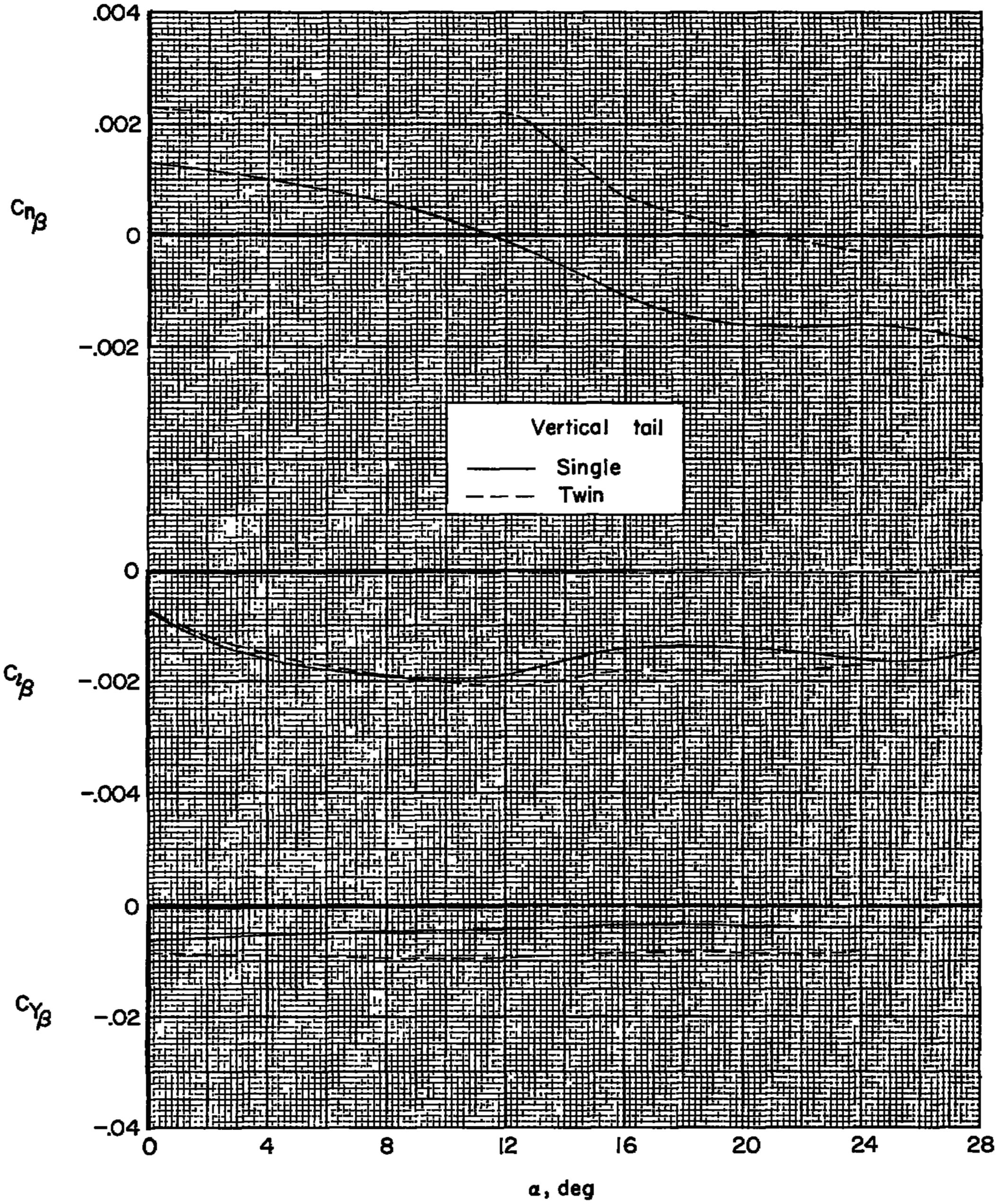
(b) Twin vertical tails.

Figure 10.- Concluded.



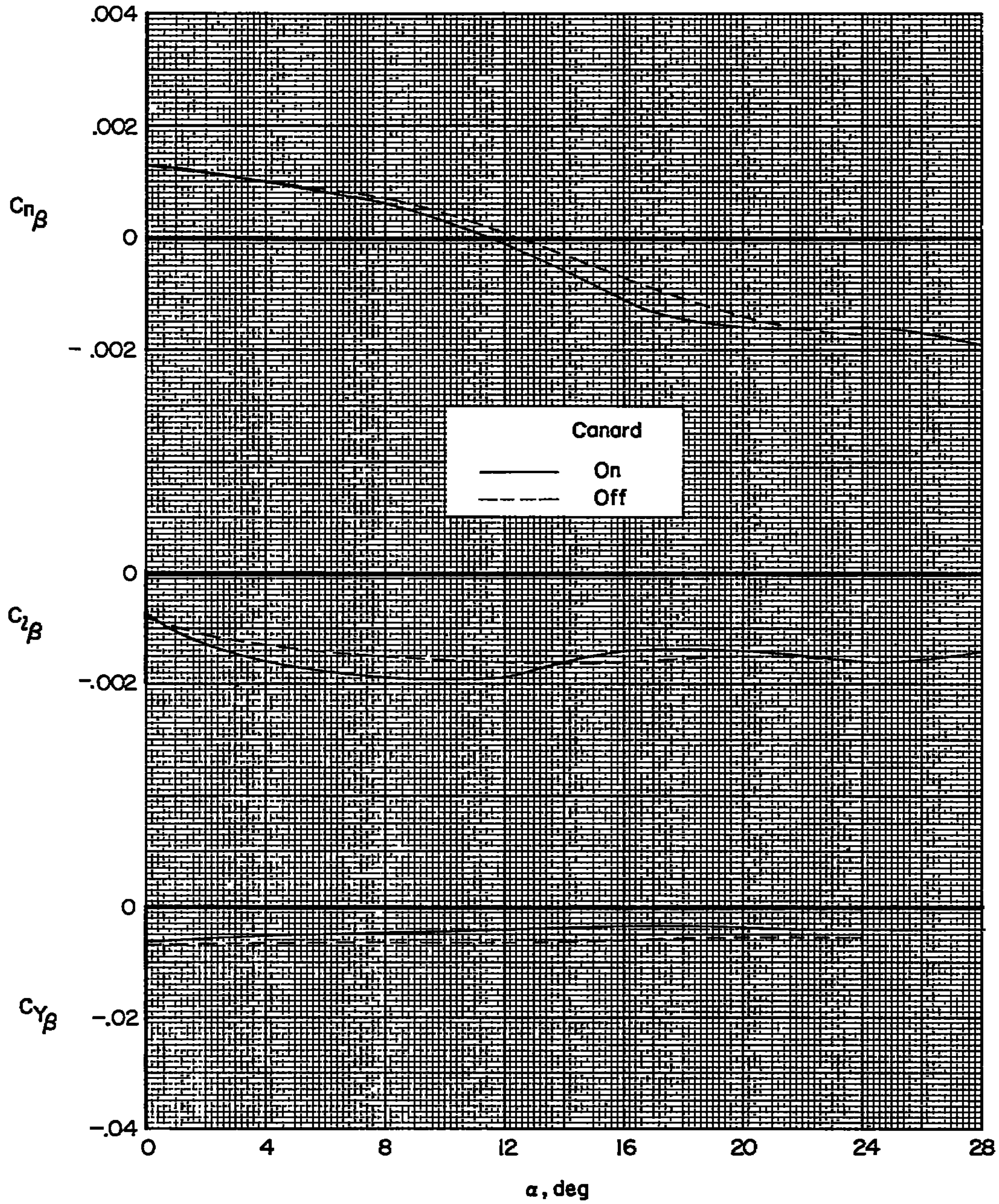
(a) Canard off; $\delta_f = 0^\circ$.

Figure 11.- Effect of vertical-tail arrangement on sideslip derivatives for model with and without canard surface.



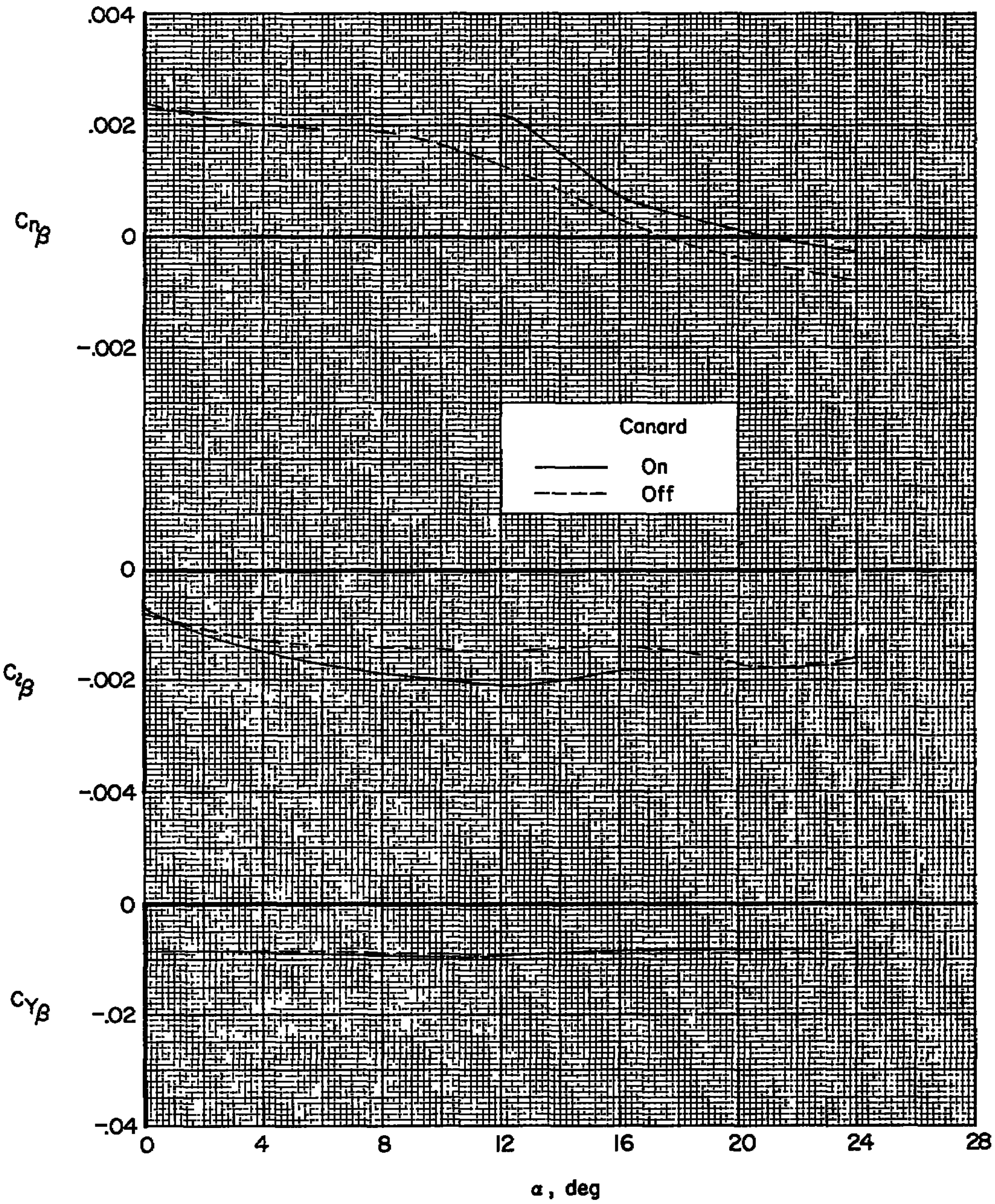
(b) Canard on; $\delta_c = \delta_f = 0^\circ$.

Figure 11.- Concluded.



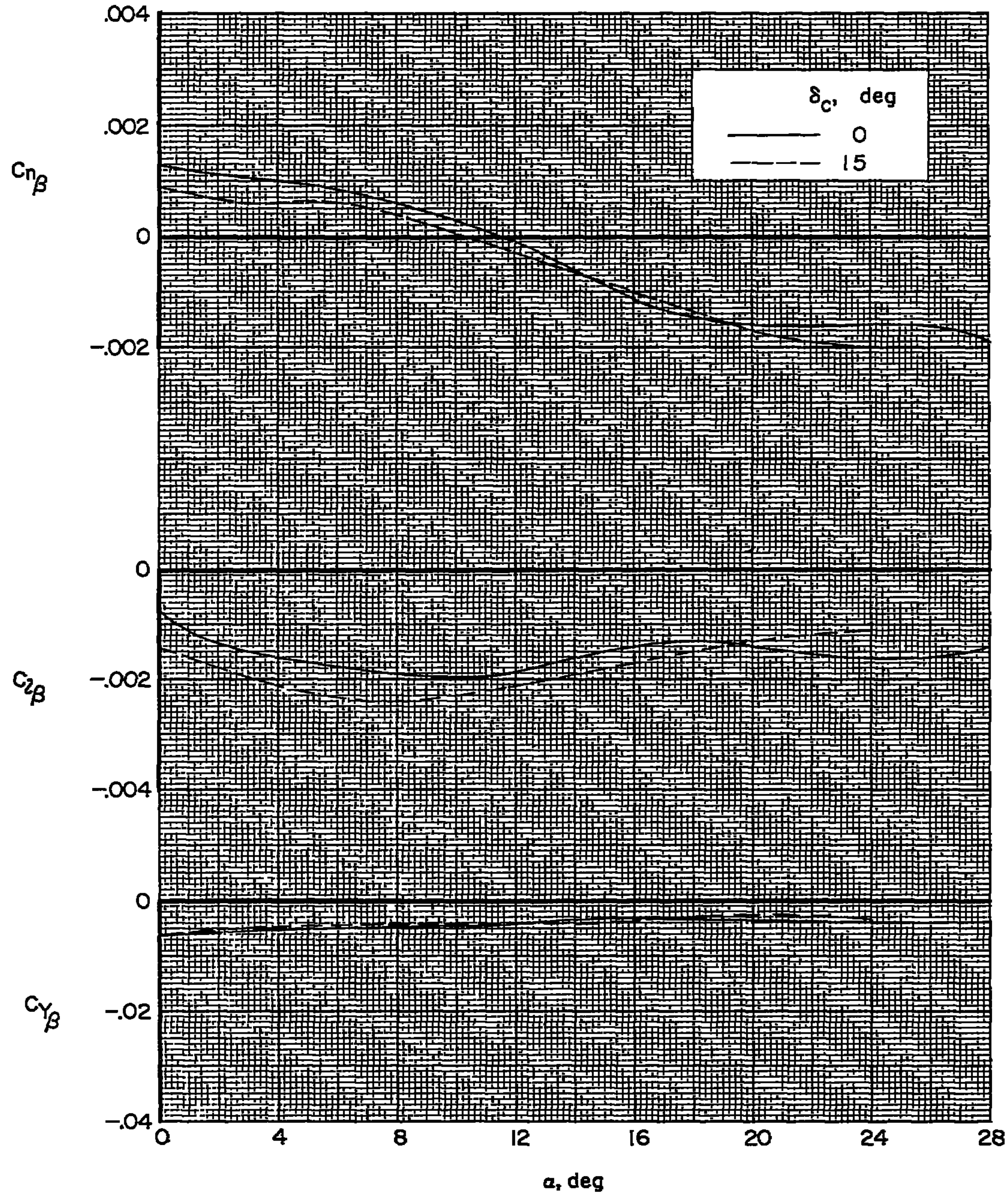
(a) Single vertical tail.

Figure 12.- Effect of canard surface on sideslip derivatives for model with single and twin vertical tails. $\delta_c = \delta_f = 0^\circ$.



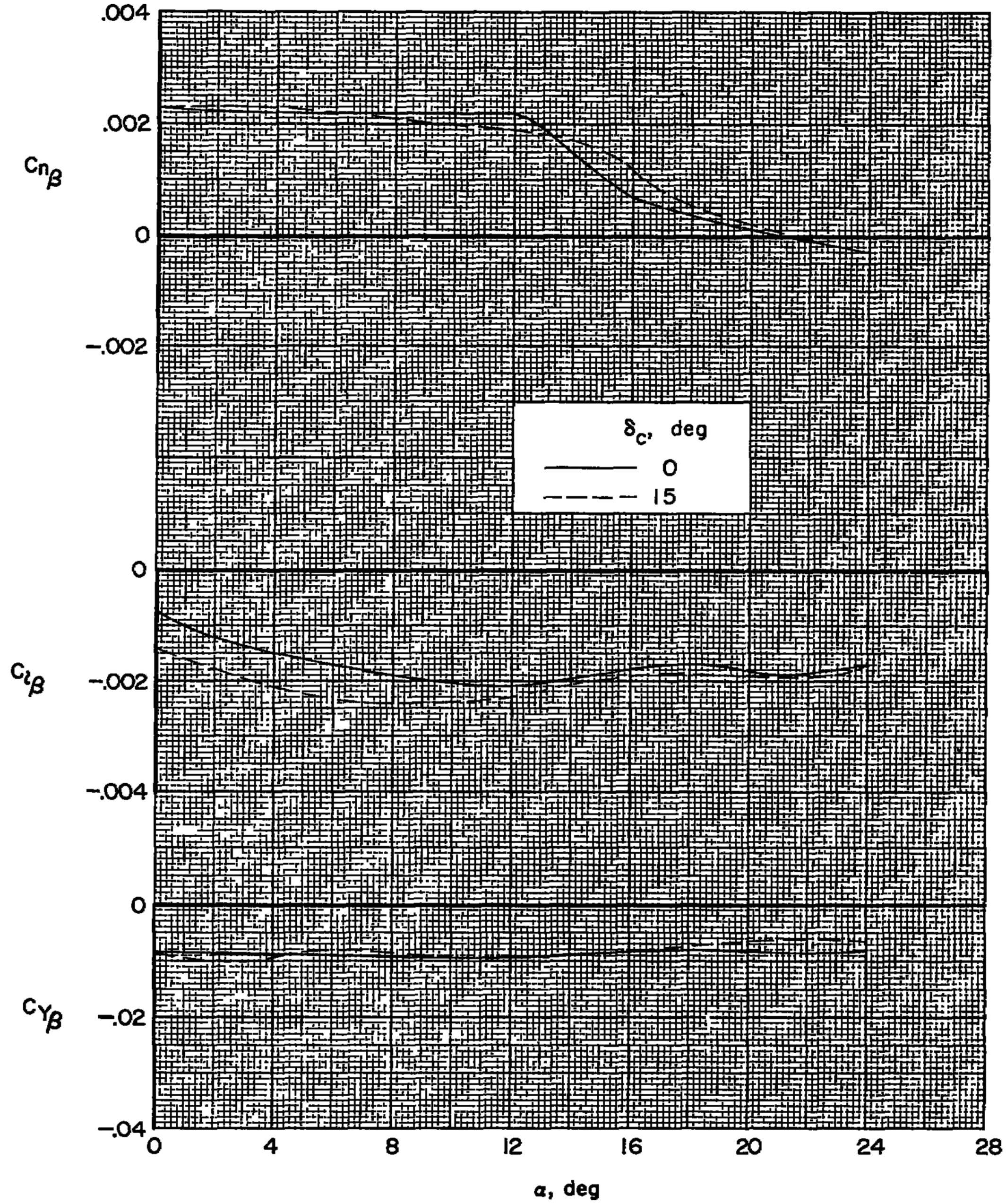
(b) Twin vertical tails.

Figure 12.- Concluded.



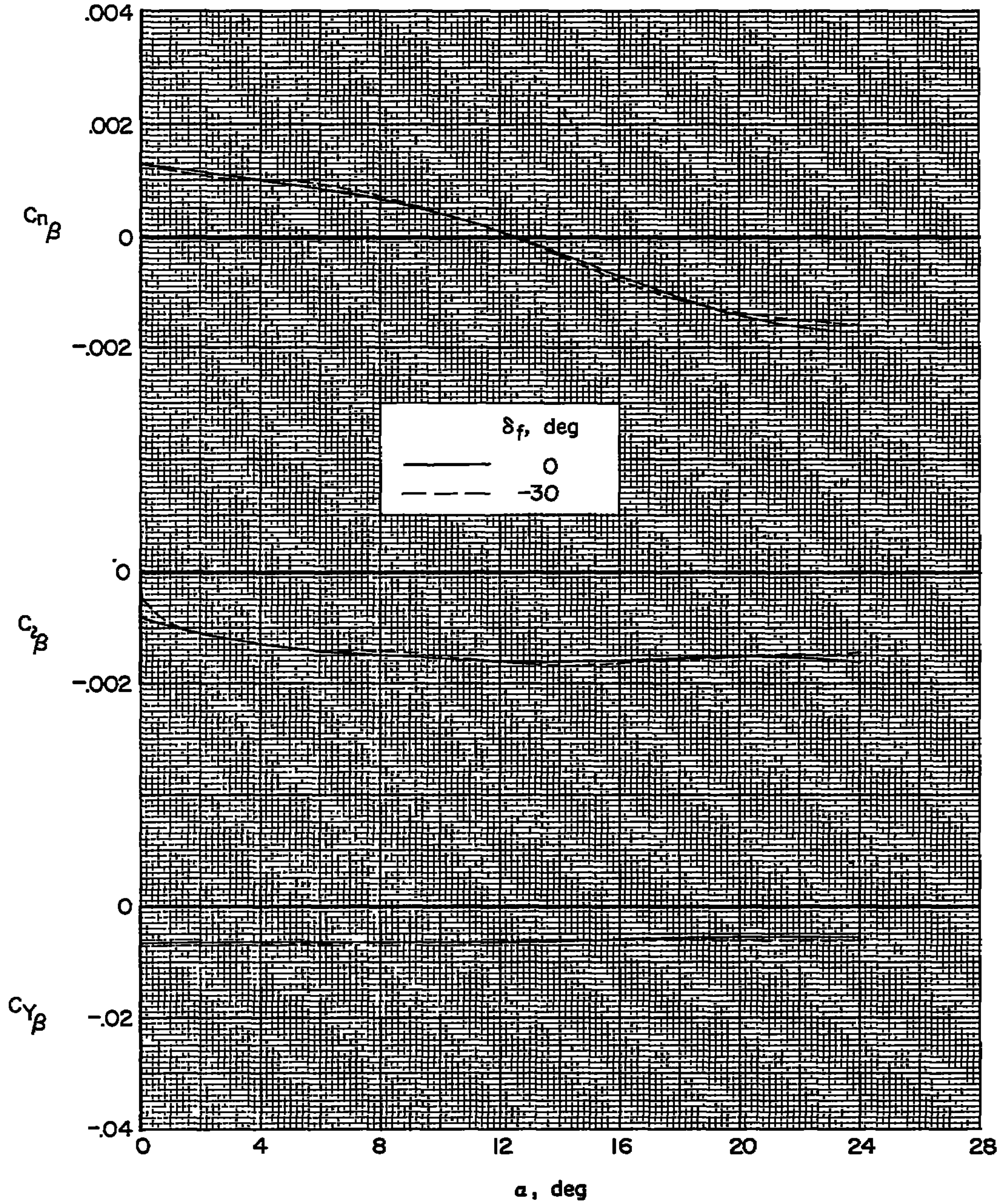
(a) Single vertical tail.

Figure 13.- Effect of canard deflection on sideslip derivatives for model with single and twin vertical tails. $\delta_f = 0^{\circ}$.



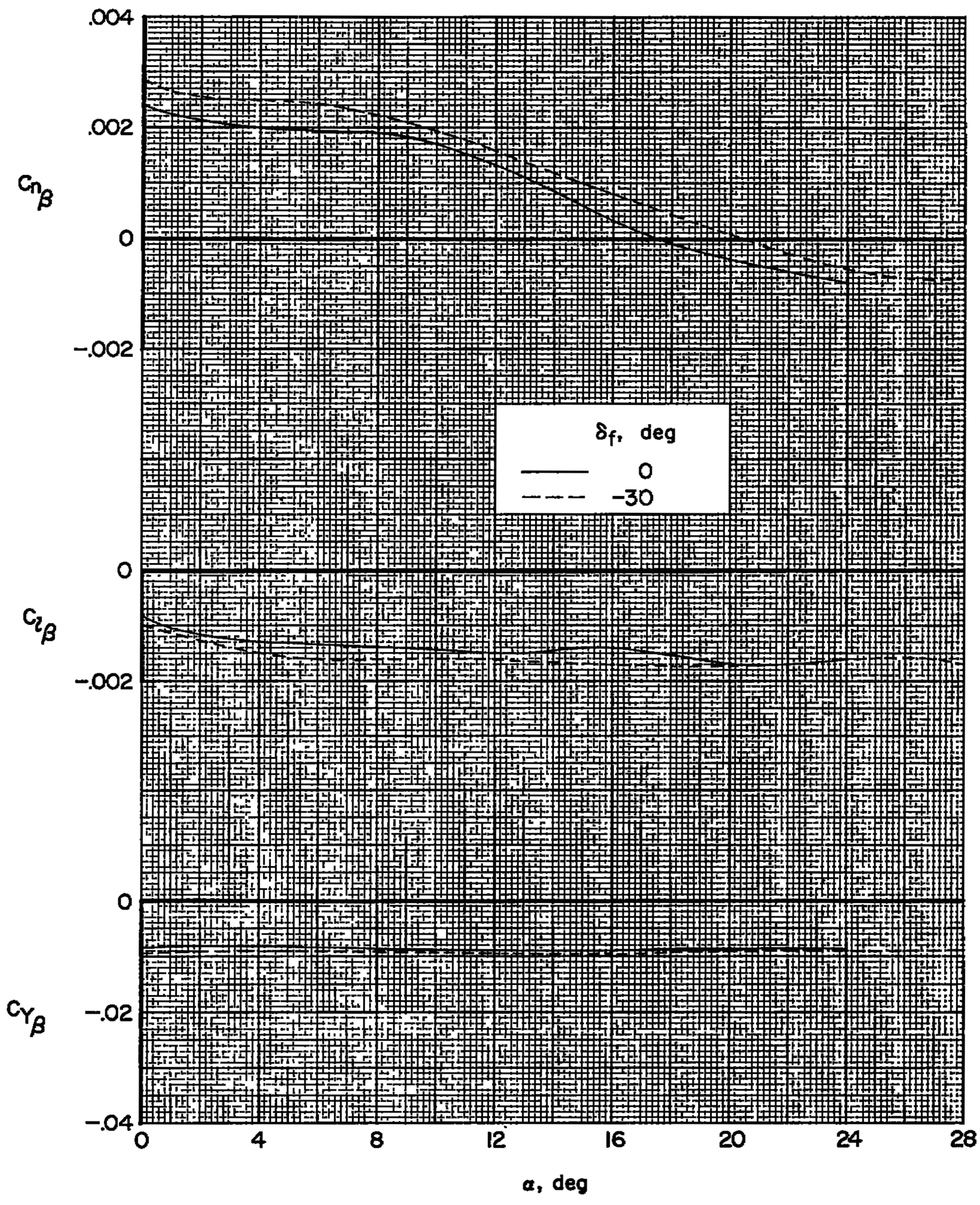
(b) Twin vertical tails.

Figure 13.- Concluded.



(a) Single vertical tail.

Figure 14.- Effect of flap deflection on sideslip derivatives for model with single and twin vertical tails. Canard off.



(b) Twin vertical tails.

Figure 14.- Concluded.

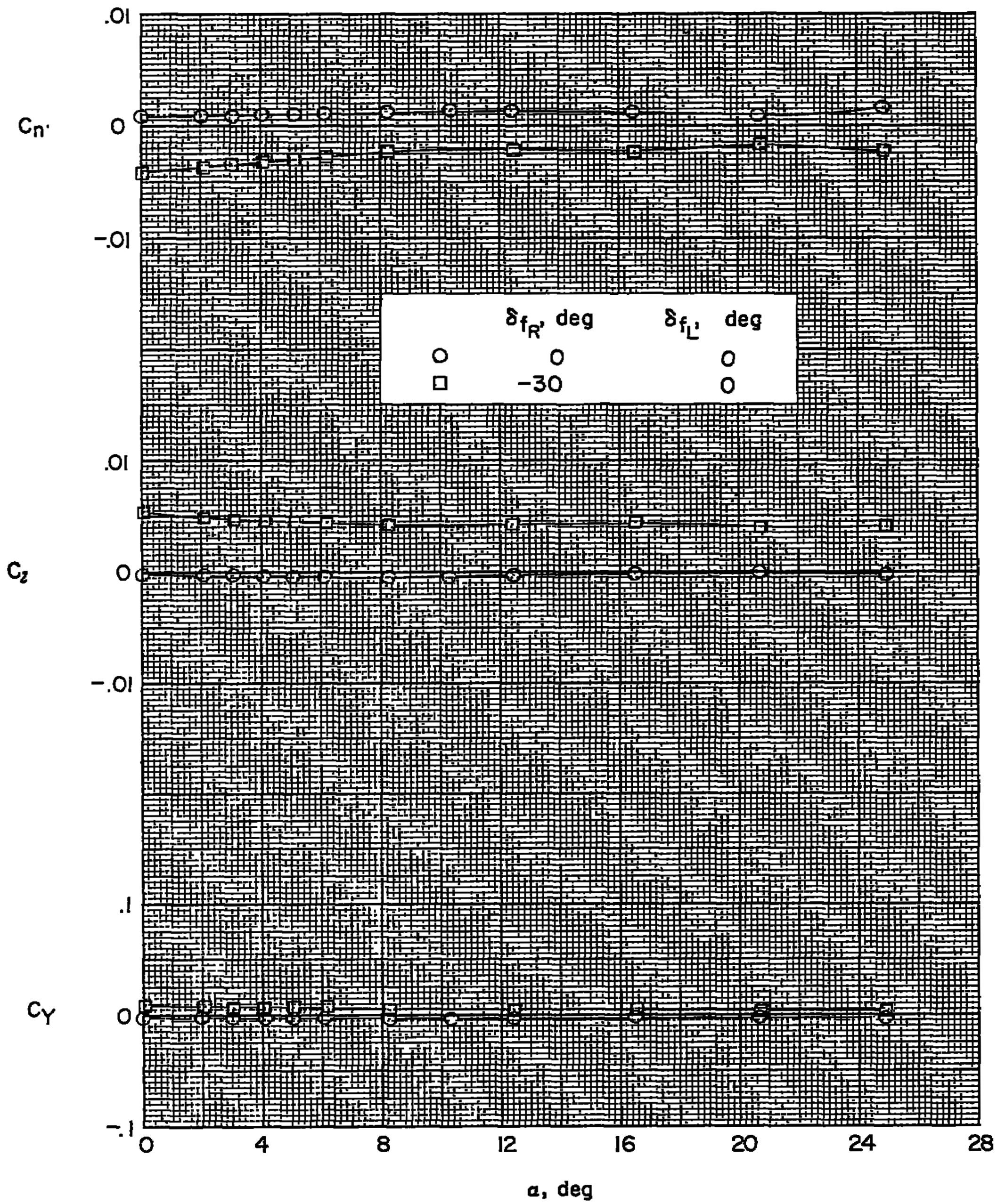


Figure 15.- Lateral control characteristics for model with twin vertical tails. $\beta = 0^{\circ}$; $\delta_c = 0^{\circ}$.

[redacted]